NASA/TM—1999-209084

Summary Report of Mission Acceleration Measurements for STS–89

Launched January 22, 1998

Kenneth Hrovat
Tal-Cut Company, North Olmsted, Ohio

Kevin McPherson
Glenn Research Center, Cleveland, Ohio

National Aeronautics and
Space Administration

Glenn Research Center

June 1999

Available from

NASA Center for Aerospace Information
7121 Standard Drive
Hanover, MD 21076
Price Code: A04

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22100
Price Code: A04

SUMMARY REPORT OF MISSION ACCELERATION MEASUREMENTS FOR STS-89

Launched January 22, 1998

Kenneth Hrovat
Tal-Cut Company
North Olmsted, Ohio

Kevin McPherson
Glenn Research Center
Cleveland, Ohio

Abstract

Support of microgravity research on the 89th flight of the Space Transportation System (STS-89) and a continued effort to characterize the acceleration environment of the Space Shuttle Orbiter and the Mir Space Station form the basis for this report. For the STS-89 mission, the Space Shuttle Endeavour was equipped with a Space Acceleration Measurement System (SAMS) unit, which collected more than a week's worth of data. During docked operations with Mir, a second SAMS unit collected approximately a day's worth of data yielding the only set of acceleration measurements recorded simultaneously on the two spacecraft. Based on the data acquired by these SAMS units, this report serves to characterize a number of acceleration events and quantify their impact on the local nature of the accelerations experienced at the Mechanics of Granular Materials (MGM) experiment location. Crew activity was shown to nearly double the median root-mean-square (RMS) acceleration level calculated below 10 Hz, while the Enhanced Orbiter Refrigerator/Freezer operating at about 22 Hz was a strong acceleration source in the vicinity of the MGM location. The MGM science requirement that the acceleration not exceed ± 1 mg was violated numerous times during their experiment runs; however, no correlation with sample instability has been found to this point. Synchronization between the SAMS data from Endeavour and from Mir was shown to be close much of the time, but caution with respect to exact timing should be exercised when comparing these data. When orbiting as a separate vehicle prior to docking, Endeavour had prominent structural modes above 3 Hz, while Mir exhibited a cluster of modes around 1 Hz. When mated, a transition to common modes was apparent in the two SAMS data sets. This report is not a comprehensive analysis of the acceleration data, so those interested in further details should contact the Principal Investigator Microgravity Services team at the National Aeronautics and Space Administration's John H. Glenn Research Center.

Acronyms and Abbreviations

DMT	Decreed Moscow Time
EORF	Enhanced Orbiter Refrigerator/Freezer
EST	Eastern Standard Time
ftp	file transfer protocol
g	acceleration due to Earth's gravitational force; 9.8 m/sec^2
GMT	Greenwich Mean Time
Hz	Hertz (cycles per second)
JSC	Johnson Space Center
KSC	Kennedy Space Center
GRC	Glenn Research Center
MET	Mission Elapsed Time
MEWS	Mission Evaluation Workstation System
mg	one millionth of g
mg	one thousandth of g
MGM	Mechanics of Granular Materials
min/max	minimum/maximum
MiSDE	Mir Structural Dynamics Experiment
MMAP	Microgravity Measurement and Analysis Project
NASA	National Aeronautics and Space Administration
pdf	Portable Document Format
PIMS	Principal Investigator Microgravity Services
PSD	Power Spectral Density
RMS	Root-Mean-Square
SAMS	Space Acceleration Measurement System
STS	Space Transportation System
TSH	Triaxial Sensor Head
URL	Uniform Resource Locator
X_H, Y_H, Z_H	SAMS sensor coordinate system axes
X_O, Y_O, Z_O	Orbiter structural coordinate system axes

Table of Contents

List of Figures

List of Tables

Acknowledgements

The author would like to thank the PIMS and SAMS teams at the NASA Glenn Research Center for their invaluable contributions to this report. In particular, the technical review, comments, and suggestions from Kevin McPherson, Melissa Rogers, and Richard DeLombard were significant and much appreciated. The formatting and editing performed by Timothy Reckart on many of the graphics in this report was also much appreciated. The processing and dissemination of the acceleration data by the SAMS team made the analyses found in this report possible.

A special thanks is owed to the Mechanics of Granular Materials (MGM) investigators, especially Roy Swanson and Susan Batiste, both with the University of Colorado. Roy and Susan provided a wealth of MGM-related correlation information and experiment operations information. Thanks also to Brad Reid of Boeing for providing the SPACEHAB module layout figure.

1. Introduction

The Space Shuttle's solid rocket boosters were ignited just after 9:48 p.m. Eastern Standard Time (EST) on Thursday, January 22, 1998. This marked the start of the 89th Space Transportation System (STS) flight (STS-89) in the National Aeronautics and Space Administration (NASA) Shuttle program, and marked the STS-89 Mission Elapsed Time (MET) of 000/00:00:00. Lifting off from the Kennedy Space Center (KSC), the crew of Endeavour embarked on a nine-day mission, which included the eighth Orbiter docking with the Mir Space Station. In addition to the docking (MET 001/17:26:05) and subsequent transfer of several thousand pounds of experiments, supplies, and hardware between the two spacecraft, Endeavour's crew conducted several science experiments in the SPACEHAB module. This module was mounted in the payload bay of the Orbiter. After the undocking from Mir at about MET 006/14:08:40, and upon successful completion of their other mission objectives, the crew of Endeavour returned to the KSC with main landing gear touchdown at about 5:35 p.m. EST on Saturday, January 31, 1998.

In order to assist microgravity science principal investigators with correlation between the acceleration environment and their experimental results, the Microgravity Measurement and Analysis Project (MMAP) at NASA's Glenn Research Center (GRC) in Cleveland, Ohio provides investigators with acceleration measurement, processing, and analysis. The primary objective was to furnish information regarding the microgravity environment to which experiments were exposed during on-orbit operations. Toward that end, experiment facilities are instrumented with accelerometers to measure the relatively minute accelerations imparted on them by various sources. For this mission, the Space Acceleration Measurement System (SAMS) was used in support of the Mechanics of Granular Materials (MGM) experiment and, for the first time, simultaneous acceleration measurements were recorded by SAMS units on the Orbiter and on the Mir Space Station. This enabled a unique opportunity to compare and contrast acceleration events as measured in the two different spacecraft comprising the mated configuration.

In this report, several significant acceleration-related events are examined in an effort to quantify and otherwise characterize their impact on the microgravity environment. Before these specifics, some background and logistical information are presented. Section 2 provides detail related to the STS-89 crew and mission payloads. Section 3 enumerates accelerometer locations and the volume of acceleration data collected during the mission. Section 4 presents a qualitative overview of the mission acceleration environment garnered from plots of the acceleration spectrum as a function of time. Section 5 is the crux of this report. It presents an in-depth look at a number of notable events as they relate to the acceleration conditions experienced both on Endeavour and on Mir. Finally, Section 6 serves to summarize the essential features of this report.

The first four appendices (Appendix A through Appendix D) for this report contain spectrograms for SAMS data collected on the Orbiter. Spectrograms computed from the SAMS data recorded on Mir during docked operations are provided in Appendix E and Appendix F. These span the time when the SAMS on Mir and the SAMS on Endeavour were simultaneously recording accelerations. Appendix G and Appendix H are comprised of interval minimum/maximum (min/max) acceleration plots for the SAMS data collected on the Orbiter. These were generated to assist the MGM researchers with their post-mission analysis. Appendix I is provided for those interested in accessing the SAMS acceleration data via the Internet. Appendix J solicits reader feedback regarding this report, and Appendix K lists the contents of the CD-ROM supplement to this report.

2. Mission Crew and Payloads

This eighth rendezvous mission with Mir was the fifth one involving an exchange of U.S. astronauts. Andrew Thomas replaced fellow astronaut David Wolf, who had been on Mir since late September of 1997. Thomas, in turn, spent approximately 4 months on the orbiting Russian facility before returning to Earth aboard Discovery, which docked with Mir in June of 1998 during the STS-91 mission. The entire STS-89 crew roster is shown in Table 1 below.

Table 1. STS-89 Crew

	Position	
Crewmember	**Description**	**Abbreviation**
Terrence Wilcutt	Commander	CDR
Joe Edwards	Pilot	PLT
James Reilly	Mission Specialist 1	MS-1
Michael Anderson	Mission Specialist 2	MS-2
Bonnie Dunbar	Mission Specialist 3	MS-3
Salizhan Sharipov	Mission Specialist 4	MS-4
Andrew Thomas	Mission Specialist 5 (up)	MS-5
David Wolf	Mission Specialist 6 (down)	MS-6

Payloads housed in the Orbiter's SPACEHAB module were targeted at various scientific tasks and included the Advanced X-Ray Detector (ADV XDT), the Advanced Commercial Generic Bioprocessing Apparatus (ADV CGBA), the Intra-Vehicular Radiation Environment Measurements by the Real-Time Radiation Monitor, the Enhanced Orbiter Refrigerator/Freezer (EORF) facility, the MGM experiment, and the SAMS. Figure 1 illustrates the layout of the SPACEHAB module for this mission. Note in particular the relative locations of the EORF, the MGM experiment, and the SAMS triaxial sensor heads (TSHs) centered on the aft bulkhead.

3. Space Acceleration Measurement System Sensor Orientations and Locations

The SAMS was manifested on this mission in support of the MGM experiment. As seen on the right side of Figure 1, one SAMS TSH, designated TSH A, was mounted adjacent to the MGM experiment location on the aft bulkhead of the SPACEHAB module. The other sensor, TSH B, was immediately below TSH A. The precise mounting orientation and location is shown in Table 2 for TSH A (serial number 402-3), and in Table 3 for TSH B (serial number 402-4). Both of these TSHs acquired acceleration data at a rate of 125 samples per second with a lowpass cutoff frequency of 25 Hz.

Table 2. STS-89 SAMS Triaxial Sensor Head A Orientation and Location

Orientation	
Orbiter Structural Axis	**Sensor Axis**
$+X_O$	$-X_H$
$+Y_O$	$+Y_H$
$+Z_O$	$-Z_H$

Location Orbiter Structural Coordinates (inches)
X_O = 1197.78
Y_O = 0.00
Z_O = 414.68

Table 3. STS-89 SAMS Triaxial Sensor Head B Orientation and Location

Orientation	
Orbiter Structural Axis	**Sensor Axis**
$+X_O$	$-X_H$
$+Y_O$	$-Y_H$
$+Z_O$	$+Z_H$

Location Orbiter Structural Coordinates (inches)
X_O = 1197.78
Y_O = 0.00
Z_O = 402.61

For this mission, each SAMS sensor axis accelerometer acquired more than 75 million measurements. All totaled, SAMS recorded nearly 2 gigabytes of acceleration data spanning more than 7 days of data collection.

4. Overview of Acceleration Environment

The vast amount of acceleration data collected by the SAMS on this mission offered a challenge for the task of data analysis. A comprehensive means of examining the data to assist in identifying significant acceleration trends and events was undertaken in the form of spectrogram plots. Spectrograms provide a broad look at how accelerations vary with respect to time and frequency. This type of plot typically spans a relatively long period of time and serves as a qualitative tool for the identification and characterization of boundaries and structure in the data. Appendices A and B contain spectrograms computed from the entire span of data collected by SAMS TSH A and TSH B, respectively. These first two appendices show the acceleration spectra up to the cutoff frequency (25 Hz) for these TSHs as a function of time. Appendices C and D do likewise, but show the spectra up to the Nyquist frequency (62.5 Hz). The plots in these appendices can be used to identify the start and stop times of specific acceleration disturbances, and show how certain spectral components of the microgravity environment vary with time (for example, see Section 5.1.3). Spectrograms can also be used to discern fundamental shifts in the ambient nature of the acceleration spectra (for example, see Section 5.2.2).

A cursory examination of the spectrograms of Appendix A provides an overview of the microgravity environment as measured by SAMS TSH A from at least two different viewpoints. First, parsing these plots from a spectral standpoint, notice that vehicle structural modes and crew activity dominated the acceleration spectra below about 10 Hz. Above this frequency, there are several items of note:

- A broadband excitation around 15 Hz that is most noticeable during crew active periods.
- A strong spectral peak that was tightly controlled in frequency at just under 16 Hz. This disturbance was of unknown origin and started at about MET 006/04:20. It continued at least until SAMS stopped recording, which was shortly after MET 007/20:40.
- A strong spectral peak that was tightly controlled in frequency at 17 Hz and originated from the dithering of the Orbiter's Ku-band antenna.
- A strong spectral peak tightly controlled in frequency at about 18.2 Hz. This disturbance of unknown origin was present when SAMS started recording, which was just before MET 000/19:20, and continued until about MET 000/20:20.
- A strong spectral peak at about 20.5 Hz that was tightly controlled in frequency and is an unknown disturbance. This disturbance started not long after SAMS started recording and was present the majority of the time until about MET 006/04:20.
- A strong intermittent spectral component introduced by the EORF at around 22 Hz, which is discussed in some detail in Section 5.1.3.
- A strong spectral peak just over 22 Hz that was tightly controlled in frequency was present when SAMS started recording and lasted until about MET 004/17:30.
- A strong, relatively brief spectral peak that started not long after MET 004/14:00 at just under 23 Hz and decreased in frequency to about 22.5 Hz when it ceased at about MET 004/14:40 (see page A-18).
- A relatively strong spectral peak that wanders in frequency above 22 Hz. This is another disturbance of unknown origin that first appeared after MET 005/00:40 and was present most of the time thereafter, at least until SAMS stopped recording.

A second perspective of Appendix A spectrograms from the time domain reveals daily broadband quieting below 20 Hz (see Section 5.1.1.1 for more detail on the crew sleep cycle), and sporadic impulsive acceleration events most notably around MET 001/17:00:00. This marked thruster firing activity as Endeavour maneuvered for its rendezvous with Mir. Further discussion on this topic is given in Section 5.2.1.

The spectrograms of Appendices A and B are quite similar. The same applies to Appendices C and D and is as expected since the two SAMS TSHs were mounted within about one foot of each other and had similar configurations. The overview presented in this section was intended to provide a qualitative overview of the microgravity environment as measured by SAMS TSH A. A more in-depth, quantitative analysis of the acceleration data is provided in Section 5 of this report.

5. Microgravity Environment

The aim of the analyses in this section is to identify, quantify, and otherwise characterize significant aspects of the microgravity environment that were measured by the SAMS. The analyses herein are not exhaustive, but serve to highlight a number of acceleration events and put some measure to their impact on the local nature of the accelerations experienced at the MGM experiment location. For those interested, further analyses of these data can be requested and tailored to specific needs simply by contacting the Principal Investigator Microgravity Services (PIMS) team at the GRC (pims@grc.nasa.gov).

This microgravity environment section is divided into two main subsections. First, the accelerations related to crew activity, experimental equipment, and those pertinent to the MGM experiment on Endeavour are presented. Second, some distinct features of the accelerations recorded on the Endeavour-Mir Complex during the docked phase of the STS-89 mission are presented.

5.1. Endeavour

STS-89 was Endeavour's 12th flight, but it's first since STS-77 in May 1996. In the interim, the Orbiter was in California for refurbishment and modifications as part of its first Orbiter maintenance down period. During that time, an external airlock was installed to support International Space Station operations. For this mission, the Orbiter was configured with the SPACEHAB module to support a number of experiments and for supply transfer with the Mir Space Station during docked operations. The crew of Endeavour had numerous objectives to accomplish over a span of less than 9 days, and the impact of their activities is discussed in the next section.

5.1.1. Crew Activity

A common and expected source of disturbance to the microgravity environment during the mission was crew movement. Experimental setups, equipment stowage, exercise, and movements between various locations were a few of the reasons for their motion. These actions necessarily involved reaction forces, which were manifested as acceleration disturbances transferred through the spacecraft structure. In this section, these crew activities are lumped together for aggregate analysis by means of comparing sleep versus wake periods. Only exercise was partitioned out for individual examination.

5.1.1.1. Sleep Versus Wake Comparison

As discussed in [1], the wake/sleep transitions evident in acceleration spectra are not sharp. That is, the measurable impact of crew motion does not suddenly stop or start with planned sleep or wake transitions, respectively. Instead, a somewhat gradual decrease or increase in the acceleration environment becomes evident at around the scheduled time of these events. However, waking is somewhat more distinct because of alarms intended to wake the crew. For an example of this, see Appendix A page A-4 just after MET 001/04:30 and Appendix A page A-5 near MET 001/11:00 for wake-to-sleep and sleep-to-wake transitions, respectively. Note in particular the quieting of the acceleration spectra below about 20 Hz. Further examination of the spectrograms in Appendix A shows regular transitions such as these that correspond to the daily sleep cycle. In addition to sleep, there are other opportunities for crew quieting from a microgravity environment standpoint. For example, see the quieting on the spectrogram of page A-22 starting at about MET 005/16:50 and lasting for approximately 45 minutes. This represents a period of time when the crew suspended normal activities to participate in a news conference.

In order to obtain a quantitative measure of the impact of crew activity on the microgravity environment, the root-mean-square (RMS) accelerations for a number of frequency bands as a function of time were calculated. These values were computed as discussed in Section 2 of [1]. The time frame for consideration was MET 001/14:15:00 to 002/14:15:00. This period spans a few hours before docking with Mir, the docking event, and over 20 hours of docked activities. As a result, simultaneous recordings by the SAMS units on the Orbiter and on Mir yield four perspectives of the acceleration environment for this time frame: two 25 Hz TSHs on Endeavour, one 100 Hz TSH on Mir, and one 10 Hz TSH on Mir. Appendix spectrograms, like those on pages A-8 and A-9, show that two transitions (one wake-to-sleep at around MET 002/01:30:00 and one sleep-to-wake at about MET 002/09:00:00) were captured by this RMS acceleration versus time analysis. The frequency bands considered for this analysis are shown in the first column of Table 4 and comments on the rationale for band selection are shown in the second column.

Table 4. RMS Acceleration Frequency Bands for Crew Activity Comparison

Frequency Band (Hz)	Comments
0.01 - 10	cutoff frequency of 10 Hz for Mir TSH B
10 - 16.93	between 10 Hz and Orbiter Ku-band antenna dither
16.93 - 17.13	Orbiter Ku-band antenna dither
17.13 - 20	between Orbiter Ku-band antenna dither and EORF
20 - 22.6	Orbiter EORF
22.6 - 25	cutoff frequency of 25 Hz for both sensors on the Orbiter
25 - 100	cutoff frequency of 100 Hz for Mir TSH A

The RMS acceleration values were computed every 65.536 seconds for both of the SAMS TSHs on the Orbiter and for the Mir SAMS TSH A, but every 40.96 seconds for the Mir SAMS TSH B as dictated by power of two considerations for frequency domain transformation. Figure 2 shows the results of these computations for the 10 to 16.93 Hz frequency band as measured on the Orbiter by SAMS TSH A. This is representative of the quieting that takes place during crew sleep. Note in particular the overall reduction in RMS acceleration levels between the 12- and 19-hour marks, which reflects the lack of crew activity. This plot shows the results from just one of the frequency bands considered for just one of the four TSHs. Table 5 summarizes the results of this analysis for the remainder of the data. Three items to note about this table are: (1) all of the RMS acceleration values shown are median values so as to minimize outlier effects, (2) values for "wake" (crew active) are to the left of the slash (/) delimiter and were computed for the periods from MET 001/14:15:00 to 001/22:15:00 and MET 002/11:15 to 002/14:15, and (3) values for "sleep" (crew inactive) are to the right of the slash (/) delimiter and were computed for the periods from MET 002/02:15:00 to 002/08:15:00.

Table 5. Median RMS Accelerations for Crew Activity Comparison

Frequency Band (Hz)	Wake / Sleep Median RMS Acceleration (μg_{RMS}) Mir TSH A (f_c = 100 Hz)	Endeavour TSH A (f_c = 25 Hz)	Endeavour TSH B (f_c = 25 Hz)	Mir TSH B (f_c = 10 Hz)
0.01 - 10	53 / 25	59 / 28	59 / 27	58 / 21
10 - 16.93	21 / 15	58 / 22	61 / 24	
16.93 - 17.13	5 / 6	77 / 105	80 / 116	← Orbiter antenna dither
17.13 - 20	12 / 12	30 / 23	31 / 23	
20 - 22.6	17 / 18	204 / 177	180 / 156	← Orbiter EORF
22.6 - 25	18 / 17	23 / 19	24 / 18	
25 - 100	1221 / 1563			

The first row of this table, corresponding to the lowest frequency band, quantifies the impact of crew activity in dramatic fashion. Comparison of the wake/sleep values shows the impact of crew movement on this band was substantial. The median RMS acceleration for wake was roughly twice that of sleep. Also, note for this band that the RMS acceleration levels at the four TSH locations within the Endeavour-Mir Complex were comparable. Further affirmation of the impact of crew activity is seen from the second lowest frequency band (10 - 16.93 Hz) for both Orbiter SAMS TSHs, but much less so for Mir SAMS TSH A. Comparing the spectra on Appendix pages A-9 and E-6 (recall Appendix E consists of spectrograms computed from Mir SAMS TSH A measurements that were recorded at the same time the SAMS on Endeavour was recording), the Orbiter/Mir disparity can be attributed to broadband excitation in this frequency range. Expectedly, as the frequency of interest increases above this second band, the measurable impact of crew activity is no longer discernible. Other disturbances, namely the EORF, can be further characterized from this analysis, however. These results will be presented in Section 5.1.3. The only TSH configured to measure accelerations above 25 Hz was SAMS TSH A on Mir. The RMS acceleration versus time for the 24-hour period starting at MET 001/14:15:00 for the spectrum measured above 25 Hz by Mir SAMS TSH A is shown in Figure 3. Note from this plot the abrupt ramp-up in RMS acceleration level starting just after the 8-hour mark. A 4-hour spectrogram that covers the time delimited by the red region of this plot, including the ramp-up, is shown in Figure 4. The sudden change in intensity coincides with the ramping down in frequency of the Mir life-support equipment signatures below 90 Hz. This most likely is attributable to a change in loading on this equipment.

The conglomeration of movements that constitute crew activity has thus far been shown to have substantial impact on the acceleration environment, particularly below 10 Hz or so. In the analysis of crew activity so far, the periods chosen were intentionally devoid of crew exercise. Exercise is best considered a special case of crew activity, whereby short duration, oscillatory movements impart relatively large magnitude accelerations.

5.1.1.2. Exercise

The impact of crew exercise on the microgravity environment has been documented for previous Shuttle missions [1, 3]. Therefore, just a couple of exercise periods from this mission are briefly examined here. The first exercise period of interest started at approximately MET 001/12:00:00 and lasted about 30 minutes (see appendix page A-6). The second started before MET 004/19:00:00 and was of comparable duration (see appendix page A-19). The first exercise period took place before docking with Mir, while the second occurred during docked operations. For the analysis here, we have considered a 4-minute slice of each exercise period — MET 001/12:18:00 to 001/12:22:00 for before docking, and MET 004/18:58:00 to 004/19:02:00 for the exercise during docked operations. The cumulative RMS acceleration versus frequency profiles for these are shown overlaid on the plot of Figure 5 along with those from some other missions. The two bold magenta traces represent the results for the exercise periods examined for this mission. As seen, there is a high degree of variability among the numerous exercises and this is attributable mainly to vigorousness of the individual who was exercising. A common aspect, however, is the spectral signature of ergometer exercise. Twin spectral peaks at the shoulder-sway and pedaling frequencies typically pop up in the vicinity of the 1.25 and 2.5 Hz regions of the acceleration spectrum, respectively. A consequence of exercise usually comes in the way of heightened structural excitation. For most of the exercise profiles, including the one labeled "STS-89 Before Docking", there is a large step in RMS acceleration just under 5 Hz. This is heightening of an Orbiter structural resonance. For the trace labeled "STS-89 During Docked", the RMS acceleration step occurs just over 5 Hz owing to the structural mode shifts, which are discussed in Section 5.2.2.

5.1.2. Mechanics of Granular Materials

The MGM experiment was developed by NASA's Marshall Space Flight Center in Huntsville, Alabama and the University of Colorado in Boulder, Colorado. Investigators on the MGM team seek a better understanding of the mechanics of granular materials or powders under low confining pressure, the force that keeps a granular material "sticking together" [4]. This has potential application in the manufacture of pharmaceuticals, mining, land conservation and management, and planetary exploration. While scientists have long experimented with soil mechanics, certain desirable test conditions are unattainable on Earth. The behavior of soils under low-confining pressures (when the soil acts like a fluid) is difficult to study under the normal gravity conditions on the ground. The low-gravity conditions of orbit afforded the MGM investigators with a new range of test conditions during STS-79 in 1996, and further investigations were pursued on this mission [5].

As discussed in Section 3, the acceleration environment experienced near the MGM experiment was monitored by two SAMS TSHs to provide acceleration measurement recordings near the phenomena under study. The MGM science requirement document called for limits of $\pm$ 1 mg [6]. Therefore, acceleration excursions that exceeded these requirements were of concern to the investigators. Post-mission analysis was sought by the MGM researchers to correlate these excursions with critical experiment times to determine if they had any discernible impact on the experiment. Toward that end, PIMS analyzed the Orbiter SAMS data for the times listed in Table 6 below.

Table 6. MGM Experiment Run Times

MET Start	MET Stop	Experiment Run
000/20:55:01	001/01:22:21	1
002/13:18:02	002/16:16:35	2
003/13:07:01	003/16:38:51	3
005/10:54:32	005/21:11:10	4
006/16:53:02	006/20:14:02	5
007/12:47:02	007/16:06:25	6

The data for the times in this table were segmented into 30-minute blocks and each block was then plotted in the form of a 1-second interval min/max plot. The results along with a complete description are detailed in Appendices G and H. One feature to note on the plots in these appendices is the pair of horizontal dashed lines denoting the MGM experiment acceleration requirements threshold. Sample stability is of concern when these limits are exceeded and the acceleration environment did sporadically exceed the experiment limits. However, in their work thus far with the STS-89 experiment results, MGM researchers have not found that any of these accelerations affected their experiment. Furthermore, correlation studies of the MGM experiment that flew on the STS-79 mission yielded the following finding [7]:

> ... compared MGM data with SAMS for STS-79. To do this, we have plotted SAMS acceleration and MGM load and pressure data (load on our sample being compressed, and water pressure surrounding our sample) and compared the three, looking for increased acceleration and unexpected load/pressure behavior occurring at the same time. During the times we examined, SAMS did record accelerations above our required limit, which concerned us due to the stability of our samples. However, most large accelerations were short-lived, which is less likely to affect our samples than continuous large accelerations. Overall, the SAMS data did not appear to correlate with our data.

Another feature to note on the min/max plots in Appendices G and H is the low frequency square wave, which is prominent throughout. This intermittent disturbance was caused by on/off cycling of the compressor of a cold storage unit, which was situated adjacent to the MGM location in the SPACEHAB module and is the topic of the next section.

5.1.3. Enhanced Orbiter Refrigerator/Freezer

The EORF was used for cold storage during the mission. As was illustrated in Figure 1, the EORF unit was housed on the aft bulkhead of the SPACEHAB module, in position AC04. This was the same position it occupied during the STS-79 mission. Section 5.3 of [8] briefly discusses the cyclic disturbance that is introduced to the microgravity environment by operation of this compressor as measured by the SAMS on that mission. For STS-79, the SAMS was mounted on the forward bulkhead of the SPACEHAB module. For STS-89, however, the two SAMS TSHs were mounted in positions AC08 and AC11 on the aft bulkhead, immediately adjacent to the EORF location. The signature of this compressor is easily recognized in the spectrograms of Appendices A through E. The train of red streaks that punctuate the spectrograms at about 21 to 22 Hz constitute the EORF signature. These spectral peaks appeared when the compressor was operating, and were absent when the compressor was off.

Comparing the operating characteristics observed during this mission to those captured by the SAMS TSHs on STS-79 and on Mir during STS-74 docked operations in 1995, it is seen that they most closely resemble that of the SAMS data collected onboard Mir during the STS-74 Atlantis-Mir docking. At that time, the EORF was flown in a forward middeck bulkhead locker. Figure 6 shows the EORF signature as measured by the Mir SAMS in November of 1995 (nominal operating frequency just under 22 Hz, and duty cycle for this time frame was at about 50% — 6 minutes on, 6 minutes off), while Figure 7 shows the EORF signature for STS-89 (nominal operating frequency just under 22 Hz, and duty cycle for this time frame was about 3.6 minutes on, 4 minutes off). Note that the PSD magnitude colorbar limits are different for Figure 6 and Figure 7. In contrast to these data, Figure 8 shows an EORF STS-79 signature that is somewhat different. The disturbance frequency exhibits damped oscillation around a nominal value of about 19 Hz, and the duty cycle seen in this figure is about 1.6 minutes on, 8 minutes off. Note that due to tradeoff considerations, the frequency resolution on this spectrogram (approximately 0.2 Hz) was intentionally degraded to improve the temporal resolution (about 2 seconds). This allows the distinctive oscillation in frequency around 19 Hz to be seen more clearly. The cause for disparity between this signature and the others is perhaps due to different cooling needs, like refrigerate versus freeze, for the different missions.

Instead of a qualitative assessment of EORF operations, a means of quantifying the effect that this disturbance had on the STS-89 microgravity environment was pursued. The 24-hour RMS acceleration versus time analysis for the crew wake/sleep comparison of Section 5.1.1.1 can be used here to provide keen quantitative insight about the EORF. The frequency band from 20 to 22.6 Hz envelopes the spectral deviation observed in the EORF signature. Thus, the plot of Figure 9 provides more detail regarding the effect of the EORF on the microgravity environment, especially at or near the MGM/SAMS location. Like the tines of a fine-toothed comb, the regularly spaced RMS acceleration peaks seen in this figure are indicative of the cyclic nature of this equipment operation. Figure 10 is a zoom-in view of this periodic disturbance. For the 2-hour period spanned in this plot, the EORF is seen to cycle on/off about 15 times with a duty cycle of approximately 3.5 minutes on and 4.2 minutes off. The duty cycle was seen to vary slightly throughout the mission. The variations are most likely due to varying temperatures, loads, or settings on the EORF. To further quantify the EORF impact, consider Figure 11. This plot is identical to Figure 9, with the exception that the peaks and valleys of the RMS acceleration values corresponding to on and off times of the EORF, respectively, are highlighted. The thick red trace marks the values associated with EORF on times, while the black trace near the bottom marks off times. The median RMS acceleration value for these off times (black trace) was 27 mg_{RMS}, while the median value for the on times (red trace) was 363 mg_{RMS}. Consequently, operation of the EORF during the period from MET 001/19:15:00 to 002/10:15:00 elevated the RMS acceleration in this frequency band by more than an order of magnitude. RMS values derived from simultaneous measurements by Mir SAMS TSH A for the same EORF frequency band are shown in Figure 12. As seen, the EORF disturbance did not discernibly carry from the SPACEHAB module to the high frequency SAMS TSH in Mir.

5.2. Endeavour-Mir Complex

While Section 5.1 addressed some features of the acceleration environment aboard the Orbiter, an interesting phase of operations started about 41 hours into the STS-89 mission. This mission was the first docking of Endeavour with the Mir Space Station and the eighth overall Mir rendezvous. The two spacecraft were docked for approximately 5 days. This phase of the mission offered a unique opportunity to analyze acceleration data collected simultaneously by two independent SAMS units, one on each of the spacecraft. The starting point for this analysis was synchronization of the timing recorded by the two instruments based on a number of acceleration data landmarks.

5.2.1. SAMS Synchronization

On the Orbiter, SAMS timing was synchronized with Endeavour's Inter-Range Instrumentation Group timing signal and it collected data continuously throughout most of the mission. On the other hand, the Mir SAMS time was synchronized with the Mir Interface to Payloads System and has historically been powered off/on as acceleration data collection needs have dictated. As a result, Mir SAMS timing requires special attention when comparing to external marks. To verify temporal alignment of the two independent SAMS data sets, acceleration data landmarks are required. In the context of this analysis, acceleration landmarks are relatively large magnitude accelerations that were easily recognizable in the data sets from both spacecraft.

5.2.1.1. Landmark #1 - Docking

The earliest possible acceleration event to consider for synchronization was the Orbiter docking with Mir. There are three time conventions mentioned with regards to the docked phase of operations: Decreed Moscow Time (DMT), Greenwich Mean Time (GMT), and MET. To convert from DMT to GMT, subtract 3 hours. To convert GMT to STS-89 MET, subtract 023/02:48:15.017 as documented in the Mission Evaluation Workstation System (MEWS) events file maintained at the Johnson Space Center (JSC). Therefore, to convert from DMT to MET, subtract 023/05:48:15.017. From the JSC STS-89 mission status report #5 for Saturday, January 24, 1998: "For the eighth time in three years, [a NASA Orbiter] is linked to the Russian space station following the successful on-time docking of Endeavour [with Mir] at 2:14 p.m. Central [Standard] Time." Appropriate conversion gives docking at GMT 024/20:14, which in turn converts to a STS-89 MET of 001/17:25:44.983. Transient peak analysis of the Orbiter SAMS data shows first motion at just before MET 001/17:26:05. Figure 13 shows the event as measured by the SAMS on both spacecraft. The first motion transient acceleration seen just before the 10-second mark on this figure was the basis for synchronization. Aligning the first positive peak in the Mir data (red trace) with the first negative peak in the Orbiter data (blue trace) shows that the Mir SAMS time led that of Endeavour by about 1.5 seconds. Note that the preceding analysis did not take propagation delay into account. It was assumed that the impulsive acceleration introduced by docking was transferred instantaneously to the two TSHs used for the synchronization.

5.2.1.2. Landmark #2 - Thruster Firing

Another event that should have registered close in time on the two spacecraft was analyzed for verification of the SAMS timing offset. The JSC MEWS database shows that Orbiter thruster firings occurred at MET 001/19:52:08.824 and 001/19:52:08.904. These are indicated by two closely spaced red vertical lines in the Orbiter data of Figure 14. Note in particular that the Y_0-axis acceleration steps in the positive direction just at the thruster firing time. Aligning first motion induced by these thruster firings in the Orbiter data with that of the Mir data shown in Figure 15 gives a Mir SAMS time lead that was less than half a second. Also, a second large transient at about the 13-second mark of Figure 14 observed on the Y_0-axis of the Orbiter data aligns with a transient in the Mir data of Figure 15.

5.2.1.3. Landmark #3 - Thruster Firing

To investigate the SAMS timing discrepancy further, another set of Orbiter thruster firing marks was studied. The JSC MEWS database provided thruster-firing times indicated by the red vertical lines on Figure 16 and Figure 17. Analysis similar to that described above resulted in a Mir SAMS time that lagged the Orbiter SAMS time by a small amount (much less than 1 second). Thus far, the trend appears to be that the Mir SAMS time was drifting monotonically with respect to that of the Orbiter SAMS. To check if that trend continued, a fourth acceleration landmark was examined.

5.2.1.4. Landmark #4 - Thruster Firing

Comparison of Figure 18 with Figure 19 gives a Mir SAMS time lead of about a tenth of a second with respect to the Orbiter SAMS time. This reversed the trend noted above, and mandates a caution that comparisons of the SAMS data recorded onboard the Orbiter and Mir should be synchronized using acceleration landmarks that are "local" to the time frame of interest. Orbiter thruster firings as maintained by the JSC MEWS database near the time frame of interest can be used.

5.2.1.5. Landmark #5 - Undocking

The Mir SAMS was powered off about 21 hours after the Endeavour-Mir docking and powered back on about 4 days later, not long before the undocking. From the JSC STS-89 mission status report #15 for Thursday, January 29, 1998: "With a gentle push from springs in the docking mechanism attaching it to the Russian Mir Space Station, Endeavour separated from the Russian space station at 10:57 a.m. Central [Standard] Time today to wrap up more than four days of joint operations and the eighth [Mir] docking mission." This corresponds to an undocking time of GMT 029/16:57:00, which for STS-89 would have been MET 006/14:08:44.983.

The Orbiter SAMS data of Figure 20 shows a not-so-gentle push took place at about MET 006/14:08:39.631. This is seen as the blip at about the 8-second mark in Figure 20. The red vertical lines in this figure indicate Orbiter thruster firings retrieved from the JSC MEWS database. These firings took place after the spring release, ostensibly to move the Orbiter away from Mir. Corroborating evidence that the blip at the 8-second mark is indeed the undocking can be gathered by comparing a short-duration power spectral density (PSD) computed just before this excursion to one computed just after it. Frequency resolution is a necessary tradeoff for temporal localization of the undocking event by this means. Figure 21 shows a before-undocking comparison of the spectral content measured by Orbiter SAMS TSH A (blue trace, MET start at 006/14:08:20.996, duration of 15 seconds) with Mir SAMS TSH B (red trace, DMT start at 029/18:41:08.201, duration of 15 seconds). Note the common modes indicated by the three arrows at about 1.8, 5.1, and 8.5 Hz, which indicate that the vehicles were mated.

In contrast to the discussion above, the 15-second spectra shown in Figure 22 were computed just after the undocking event. Here, the cluster of structural modes around 1 Hz on the red trace are intrinsic to the Mir microgravity environment, while the modes at and above 5 Hz on the blue trace are unique to the Orbiter. A closer look at the Orbiter time domain data reveals that the Z_0-axis registered a relatively large peak acceleration (4.7 mg) from the undock event just after the 1.5-second mark in Figure 23. This is marked by the red vertical lines in the figure and the polarity ($-X_O$, $+Z_O$) is consistent with a pitch-down of Endeavour as it reacted to the spring force according to Newton's third law of motion. From the Mir SAMS data of Figure 24, it appears that the undock spring push occurred at the Mir SAMS recorded timestamp of DMT 029/18:41:38.213, shortly after the 30-second mark on this figure. Note that the Y-axis Mir SAMS accelerometer registered a peak acceleration of 4.7 mg at this time, which matches that of the Orbiter SAMS Z-axis accelerometer. Therefore, the Mir SAMS timestamps lag the Endeavour SAMS timestamps by more than 1 hour and 15 minutes for this undock timeframe. Operationally, this can be accounted for by inaccurate synchronization of the Mir SAMS at turn-on time after a prolonged powered-off interval during docked operations. The Mir SAMS unit stopped recording just before MET 002/14:20:00 as seen on Appendix pages E-7 and F-7. The timestamps shown in Appendices E and F were converted from DMT to MET by subtracting 23 days, 5 hours, 48 minutes, and 15 seconds. This reinforces the point that care must be taken when comparing the SAMS data recorded "simultaneously" on Mir and on the Orbiter.

Table 7 serves to summarize the synchronization results of this section. The Orbiter SAMS timing was consistently in close accordance with external marks, while the Mir SAMS was offset somewhat. In this table, the time for a given event was gleaned from the recorded SAMS data and is shown as a MET in the 2nd column. The GMT column was derived from the MET by adding the STS-89 launch time (MET 000/00:00:000 = GMT 023/02:48:15.017). The year 1998 is implied. The conversion to DMT should be a matter of adding 3 hours to the GMT, but the DMT column in Table 7 shows the time inferred from the Mir SAMS TSH B data. The rightmost column represents the difference between the GMT-to-DMT conversion value (3 hours) and the difference between the previous two columns. If all the timing were synchronized, then the time difference shown in the last column would have been zero.

Table 7. Mir SAMS Time Offsets Relative to Orbiter SAMS Time

	Orbiter SAMS		Mir SAMS	Mir SAMS
Event	**MET**	**GMT**	**DMT**	**Time Offset (seconds)**
Docking with Mir	001/17:26:04.821	024/20:14:19.838	024/23:14:21.409	+1.571
Landmark #2	001/19:52:08.824	024/22:40:23.841	025/01:40:24.263	+0.422
Landmark #3	001/20:42:06.584	024/23:30:21.601	025/02:30:21.546	-0.055
Landmark #4	001/21:21:20.024	025/00:09:35.041	025/03:09:35.180	+0.139
Undocking from Mir	006/14:08:39.631	029/16:56:54.648	029/18:41:38.213	-4,516.435

5.2.2. Structural Modes

The previous section dealt with determining the precise timing of various acceleration events, including the Mir docking. Another, less precise, means of localizing the time when the two independent spacecraft structurally became one is by making low frequency spectral comparisons. Before docking, the individual spacecraft resonated at their own structural mode frequencies. Soon after docking, when the two spacecraft were hard-mated to form the Endeavour-Mir Complex, new structural mode resonance frequencies became evident. This section focuses on this structural mode regime transition.

The rendezvous with Mir during this mission offered a unique opportunity to analyze the microgravity environment as measured simultaneously by the SAMS units both on Endeavour and on Mir. In particular, when the two vehicles were mated, the structural mode regimes for each underwent a change from each of their own environments toward a common one. For a spectral overview of this transformation, see the transition that occurs at MET 001/17:26:04.821 on the spectrograms of Appendix pages A-6 and F-3. These spectrograms represent measurements taken by the SAMS on the Orbiter and on Mir, respectively. On page A-6 for example, the prominent Orbiter modes close to 5 Hz become less distinct after docking, while a new spectral cluster springs up at around 1 Hz.

For a more in-depth look at the spectral transition that occurs as a result of mating the two vehicles, two periods were considered for comparative analysis. For the discussion that follows, the 3-hour span starting at MET 001/13:51:44 is designated the before-docking period, while the 6-hour span starting at MET 001/18:00:00 is designated the during-docked period. Before interpreting the results, however, let it be clear that the analysis performed in this section was not intended to be a comprehensive study of the structural dynamics of the Orbiter, Mir, or the mated configuration. The primary objective of the SAMS was to characterize the microgravity environment for experiments to which the TSHs were mounted. A more detailed characterization of the structural dynamics of Mir and of the mated configuration is given in the final report of the Mir Structural Dynamics Experiment (MiSDE) [9].

5.2.2.1. Before-Docking Period

Figure 25 is an overlay of two spectrograms for the before-docking period. The thin vertical white line at the midway point of the time axis indicates where two data sets are juxtaposed. Data recorded by SAMS TSH B on Mir are to the left of this white line, while SAMS TSH B data recorded on the Orbiter are to the right. Note that the time axis ticks are recycled at the midway point to indicate that these data were recorded simultaneously. The spectrograms from these two data sets were concatenated in this manner to facilitate comparison and highlight the contrast between the structural mode regimes of the two individual vehicles before they were mated. As expected, the acceleration spectrum of Mir is noticeably different than that of the Orbiter. The energy on the Mir side (left side) is concentrated in several structural modes below 2 Hz, while for the Orbiter side (right side), it is distributed over relatively fewer, more diffuse structural modes above 3 Hz. In order to quantify these observations, long-duration PSDs were computed for the before-docking period using Welch's Method as described in [2]. The parameters used to compute these are shown in Table 8.

Table 8. Parameters for Long-Duration, Before-Docking PSDs

	Number of Points Per PSD	Time Spanned Per PSD (seconds)	Number of PSDs in Spectral Average
Orbiter SAMS TSH B	8192	65.536	111
Mir SAMS TSH B	4096	81.920	132

Segments of data that contained an impulsive acceleration (those in excess of 10 mg) were not included in the spectral averaging process. Therefore, note that the number of spectral averages for the Orbiter data tallies to a total of just over 2 hours owing to the numerous impulses introduced to the Orbiter environment by rendezvous maneuvers. If there had been no Orbiter-born accelerations in excess of 10 mg, then this total would be approximately 3 hours. The resultant long-duration PSDs for the before-docking period are shown in Figure 26. Examination of these PSDs reinforces that the dominant structural modes for the Mir environment are below 2 Hz, and are primarily clustered around 1 Hz. Not shown in this figure is the PSD for the second Orbiter sensor, SAMS TSH A. The acceleration spectrum below 10 Hz for this TSH closely matches that displayed as the blue trace in the figure, thus it was omitted. Applying Parseval's Theorem to the "MIR TSH B" PSD (the red trace) of Figure 26 as presented in [2], yields the results shown in Table 9. Note that the rightmost column's page numbers are in reference to a detailed report on the structural dynamics of Mir and the mated configuration [9].

Table 9. Mir Structural Mode RMS Accelerations for Before-Docking Period

Frequency (Hz)			RMS Acceleration (μg_{RMS})	MiSDE Report Page
Lower	Center	Upper		
0.45	0.48	0.49	7	
0.49	0.54	0.62	33	
0.62	0.68	0.77	9	2-8
0.77	0.82	0.83	8	5-11
0.83	0.85	0.92	19	5-6
1.04	1.07	1.12	18	
1.12	1.15	1.19	13	2-8
1.27	1.28	1.31	9	5-9
1.31	1.34	1.37	11	
1.37	1.40	1.44	15	5-9
1.87	1.89	1.90	5	
1.90	1.94	1.98	10	2-8

Note from this table that the strongest Mir mode registered by the SAMS for the before-docking period resides at about 0.54 Hz. Parseval's Theorem was next applied to the "ORBITER TSH B" PSD (the blue trace) of Figure 26 to obtain the values shown in Table 10.

Table 10. Orbiter Structural Mode RMS Accelerations for Before-Docking Period

Frequency (Hz)			RMS Acceleration (μg_{RMS})
Lower	Center	Upper	
3.94	4.01	4.07	8
4.64	4.91	5.19	36
6.18	6.26	6.36	6
6.44	6.52	6.58	5
7.34	7.46	7.51	8
7.51	7.55	7.63	7
7.81	7.90	8.03	10
9.57	9.64	9.75	4

Note from this table that the strongest Orbiter structural mode registered by the SAMS for the before-docking period was at about 4.91 Hz. Also, the presence of the structural modes listed in the first two rows of Table 10 is consistent with previous measurements made on Atlantis during the undocked phase of the STS-79 mission [8]. After the structural mode regimes of the two individual spacecraft were examined, analysis of the acceleration spectrum below 10 Hz for the Endeavour-Mir complex was performed.

5.2.2.2. During-Docked Period

At MET 001/17:26:04.821, Endeavour was mated with Mir to give rise to the Endeavour-Mir complex. Figure 27 is an overlay of two spectrograms for the during-docked period. The thin vertical white line at the midway point of the time axis indicates where the two data sets are adjoined. Data recorded by SAMS TSH B on Mir are to the left of this white line, and SAMS TSH B data recorded on the Orbiter are to its right. Note that the time axis ticks are recycled at the midway point to indicate that these data were recorded simultaneously. The spectrograms from these two data sets were brought together in this manner to facilitate comparison and highlight the commonality of the structural mode regimes measured in the two vehicles of the Endeavour-Mir complex. It is quite clear from this figure that when considering principal spectral contributors below about 10 Hz, the two independent SAMS units measured a common set with few exceptions. The last column of Table 11 flags some significant spectral responses measured by the SAMS on one of the spacecraft, but not the other.

Table 11. During-Docked Period Structural Mode RMS Accelerations for Endeavour-Mir

Frequency (Hz)			RMS Acceleration (μg_{RMS})		MiSDE Report Page(s)	Comments
Lower	Center	Upper	Mir	Orbiter		
0.07	0.12	0.23	17	20	5-5, 5-6	
0.23	0.31	0.38	14	13	5-5, 5-6	
0.67	0.83	0.93	23	9	5-5, 5-6, 5-8	
1.01	1.06	1.16	18	6	5-6, 5-8	Orbiter: 1.11 Hz
1.27	1.38	1.43	10	4	5-5, 5-6, 5-8	
1.72	1.78	1.84	7	7	5-6	
1.84	1.89	1.93	6			Mir only
2.23	2.44	2.71	13	6	5-6	
3.09	3.38	3.66	32	8		
3.82	3.89	3.95		4		Orbiter only
4.39	4.53	4.64		8		Orbiter only
4.85	5.04	5.24	15	33		
6.1	6.27	6.46		8		Orbiter only
6.5	6.59	6.69		8		Orbiter only
7.34	7.9	8.65	19	32		
9.41	9.57	9.67		8		Orbiter only

The peak at 1.06 Hz was as measured by the Mir SAMS. This response was weaker and slightly higher in frequency (at about 1.11 Hz) in the Orbiter SAMS data. Again, the penultimate column cites pages from [9], a good source for detail regarding these structural modes.

6. Summary

In this report, a number of acceleration-related events were analyzed in an effort to characterize and, in some cases, quantify their impact on the microgravity environment. From a survey of the SAMS TSH A color spectrograms of Appendix A, several significant disturbances of unknown origin were presented. Most of these were tightly controlled in frequency, which suggests rotating or cyclic machinery operations. Crew activity was shown to elevate the median RMS acceleration level computed below 10 Hz from under 30 mg_{RMS} to about 60 mg_{RMS}. Their effect on the acceleration spectrum above about 20 Hz was not discernible. The MGM science requirement that the acceleration not exceed ± 1 mg was violated numerous times during their experiment runs. Thus far in their investigation, however, no correlation with sample instability has been found. The EORF was a relatively strong acceleration source in the vicinity of the MGM location. It operated between 20 and 23 Hz for nearly the duration of the mission with a duty cycle of roughly 4 minutes on, and 4 minutes off. Calculations showed that operation of the EORF increased the median RMS acceleration level in the frequency band 20-22.6 Hz by more than an order of magnitude from under 30 mg_{RMS} to over 300 mg_{RMS}. Synchronization between the Mir SAMS data and the Endeavour SAMS data was shown to be close most of the time, but caution with respect to exact timing should be exercised when comparing these data. When orbiting as a separate vehicle prior to docking, Endeavour had prominent structural modes above 3 Hz, and these were not as tightly bound in frequency as the cluster of modes observed around 1 Hz in the Mir data. When mated, common modes were readily apparent in data collected by the SAMS on both spacecraft.

This report is not a comprehensive analysis of the two sets (Endeavour and Mir) of SAMS data available from the STS-89 mission. Instead, the objective was to characterize a number of acceleration events and quantify their impact on the local nature of the accelerations experienced at the MGM experiment location. For those interested, further analyses of these data can be requested and tailored to meet specific needs by contacting the PIMS team via e-mail at pims@grc.nasa.gov or at the following address:

PIMS Project Manager
NASA Glenn Research Center
21000 Brookpark Road MS 500-216
Cleveland, OH 44135

7. References

[1] Rogers, M. J. B., Hrovat, K., McPherson K., & Reckart, T. (1999) Summary Report of Mission Acceleration Measurements for STS-87. NASA Technical Memorandum 1999-208647.

[2] Rogers, M. J. B., Hrovat, K., McPherson K., Moskowitz, M., & Reckart, T. (1997) Accelerometer Data Analysis and Presentation Techniques. NASA Technical Memorandum 113173.

[3] Moskowitz, M., Hrovat, K., Tschen, P., McPherson K., Nati, M., & Reckart, T. (1998) Summary Report of Mission Acceleration Measurements for MSL-1. NASA Technical Memorandum 1998-206979.

[4] http://www.ksc.nasa.gov/Shuttle/missions/sts-89/sts-89-press-kit.txt

[5] http://science.msfc.nasa.gov/newhome/headlines/msad06jan98_1.htm

[6] personal communication with Roy Swanson, 10/14/1998

[7] personal communication with Susan Batiste, 01/20/1999

[8] Rogers, M. J. B., Hrovat, K., Moskowitz, M., & Reckart, T. (1997) Summary Report of Mission Acceleration Measurements for STS-79 Launched September 16, 1996. NASA Contractor Report 202325.

[9] Kim, H., Kaouk, M. (1998) Final Report - Mir Structural Dynamics Experiment. NAS15-10000.

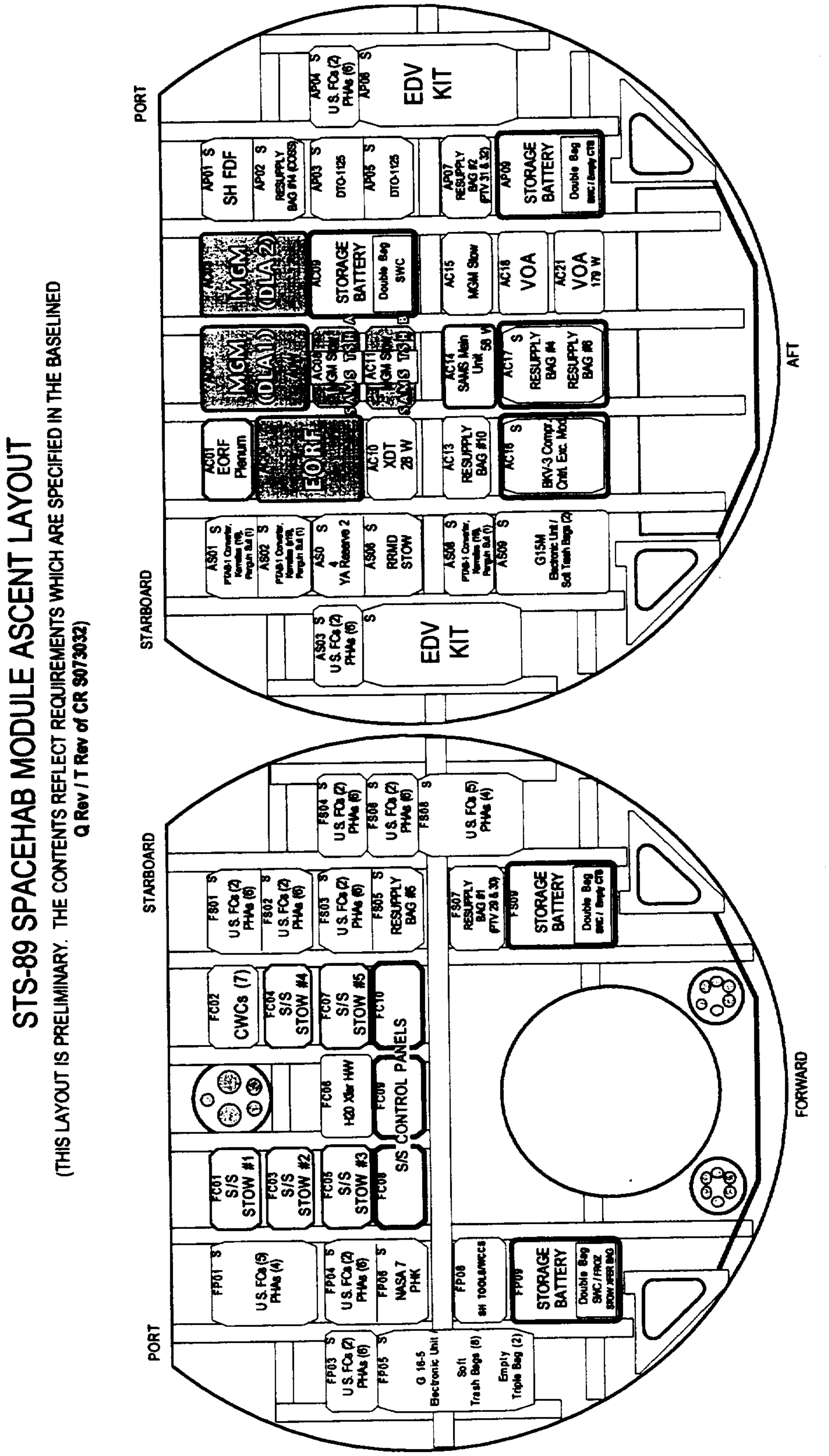


Figure 1. SPACEHAB Module Layout Diagram

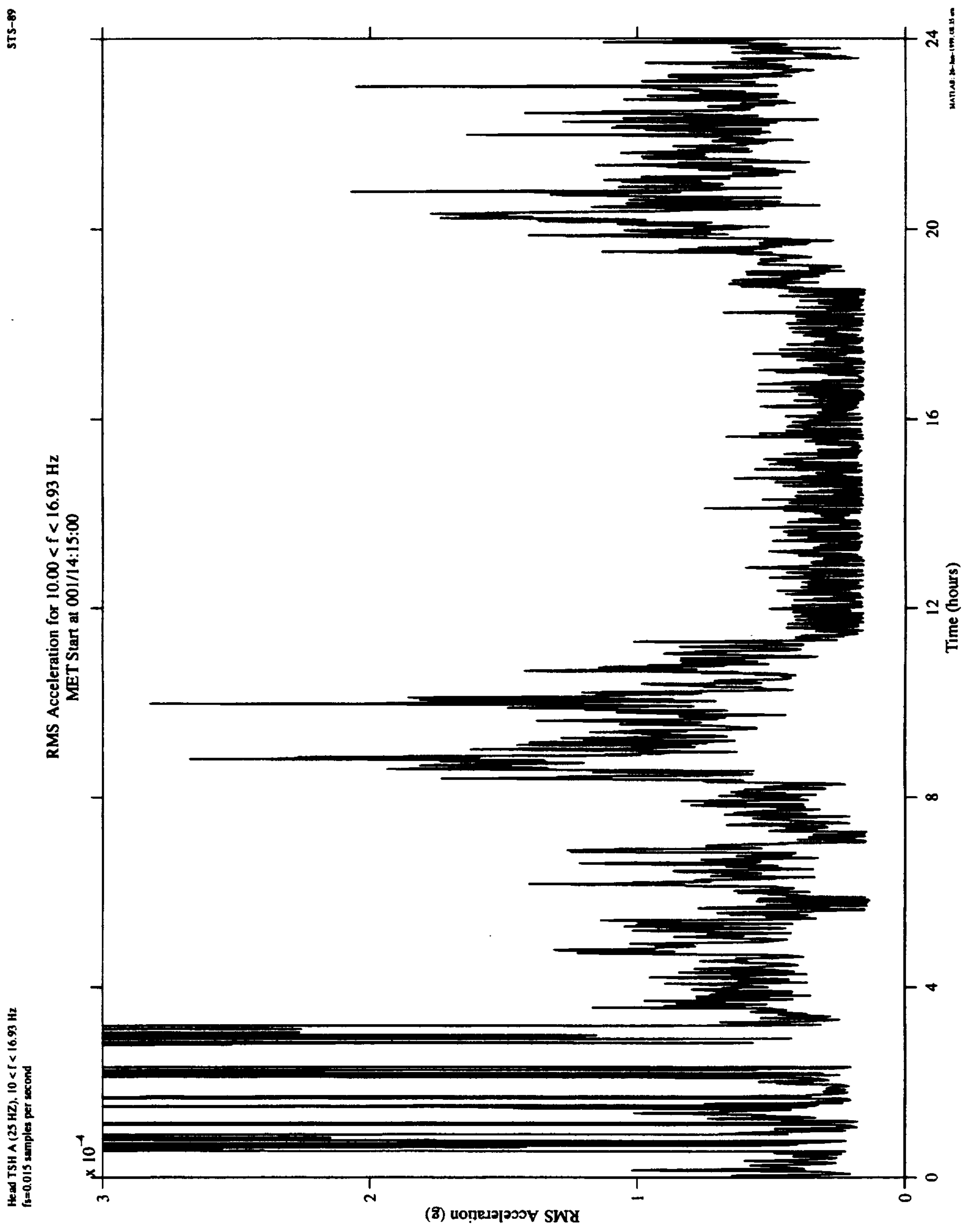


Figure 2. RMS Acceleration Versus Time (10 < f < 16.93 Hz), Orbiter SAMS TSH A

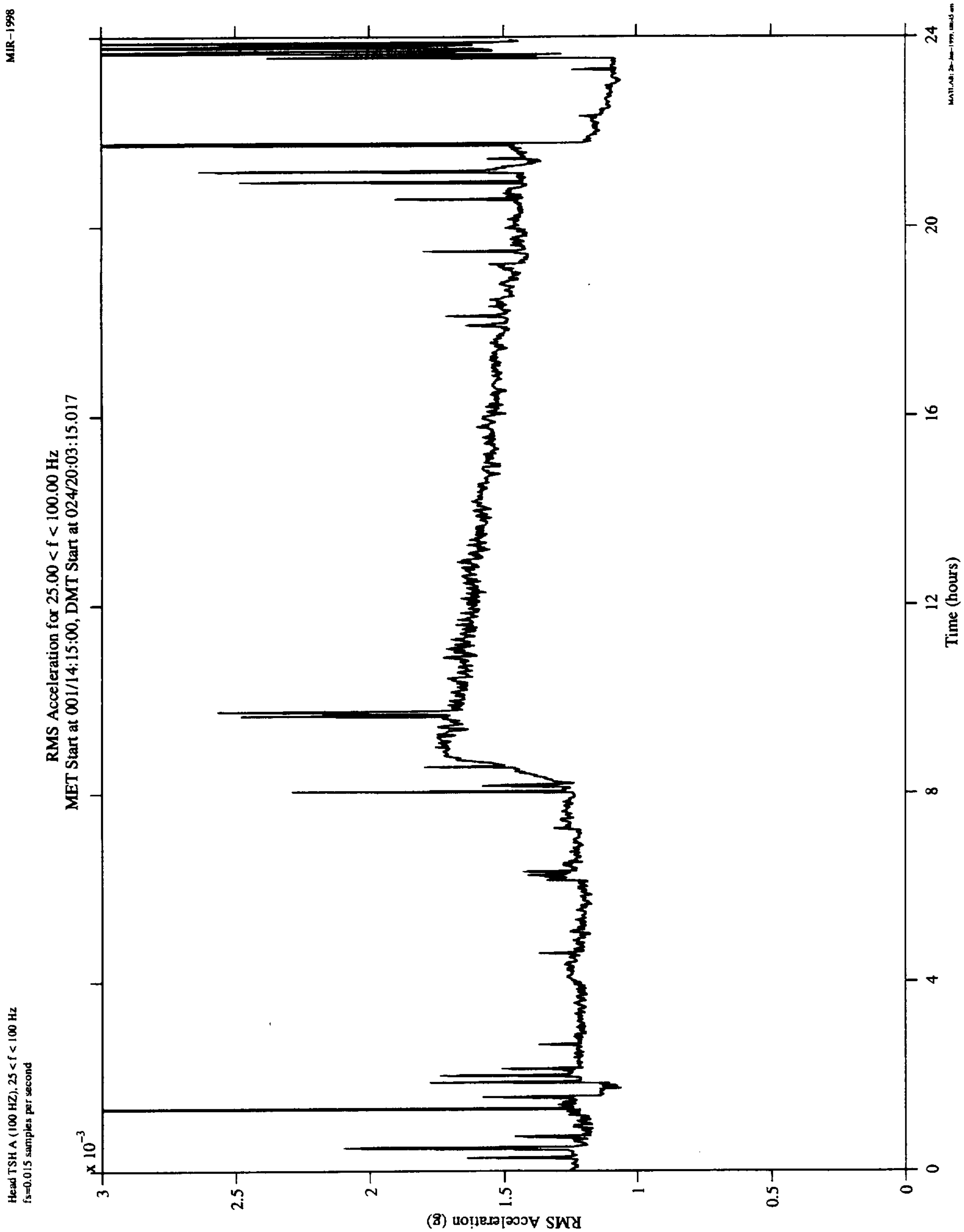


Figure 3. RMS Acceleration Versus Time (25 < f < 100 Hz), Mir SAMS TSH A

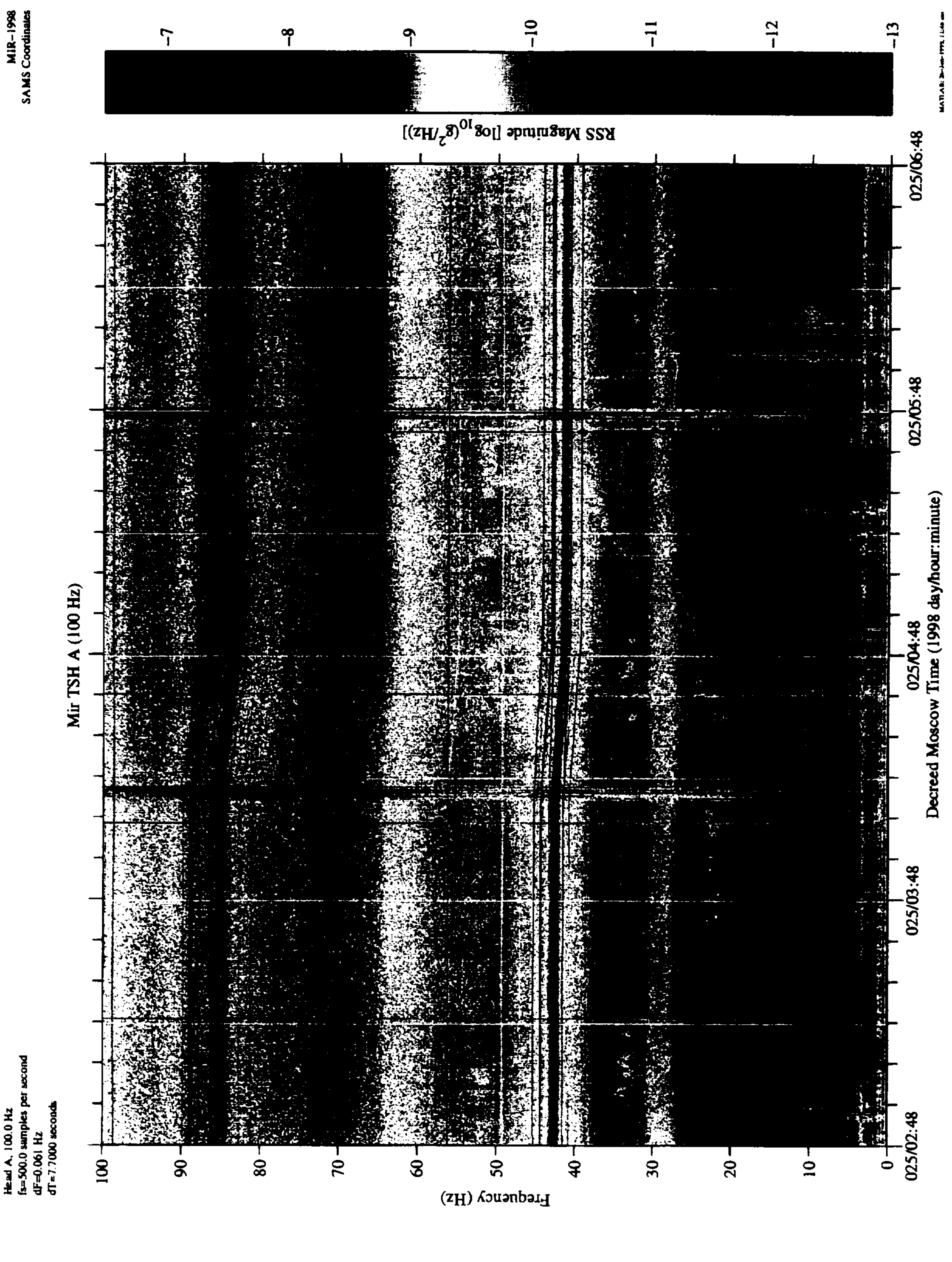


Figure 4. Spectrogram Featuring Mir Life-Support Equipment, Mir SAMS TSH A

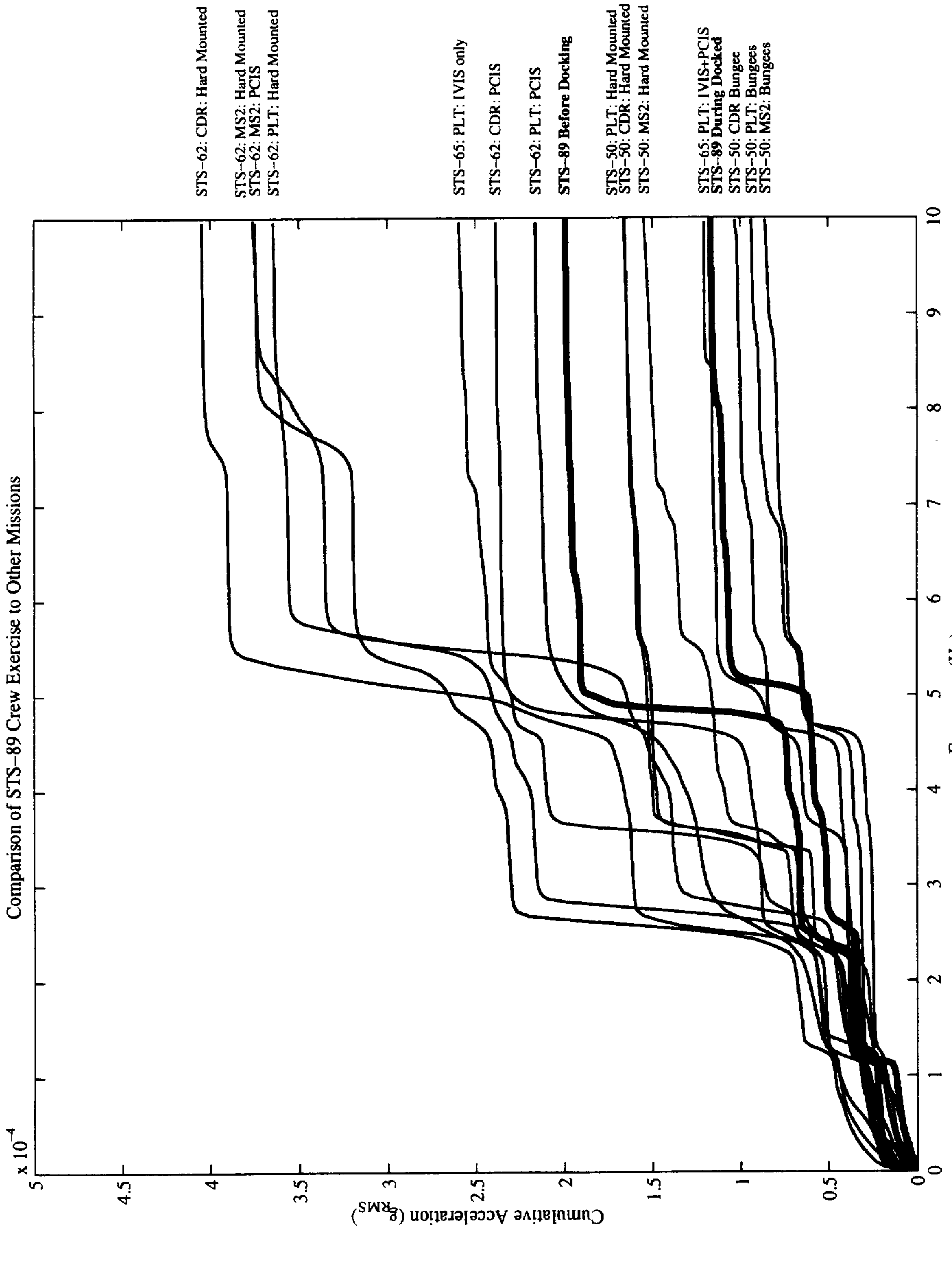


Figure 5. Cumulative RMS Acceleration versus Frequency for Exercise Comparison

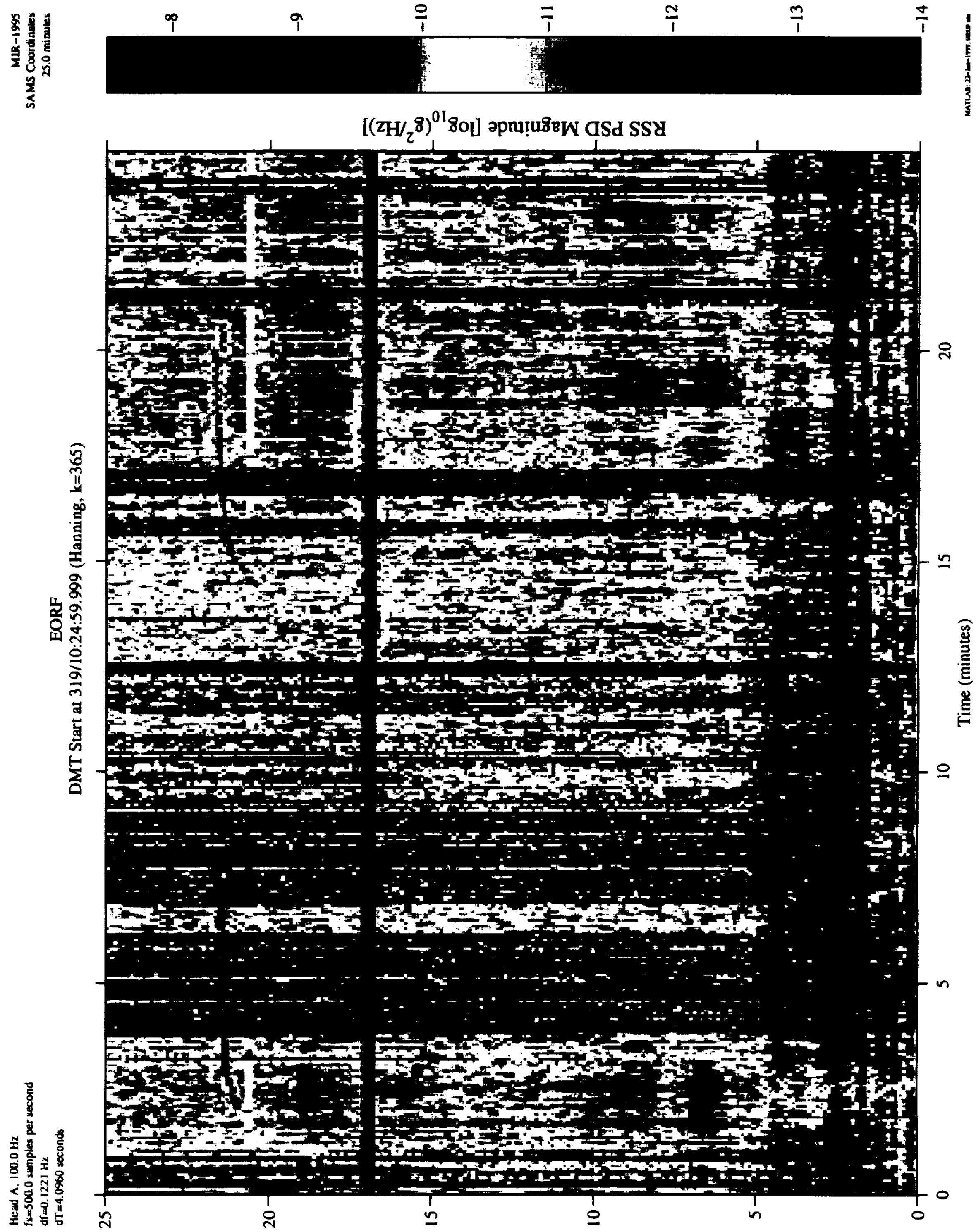


Figure 6. Spectrogram Featuring EORF Signature, Mir SAMS TSH A (1995)

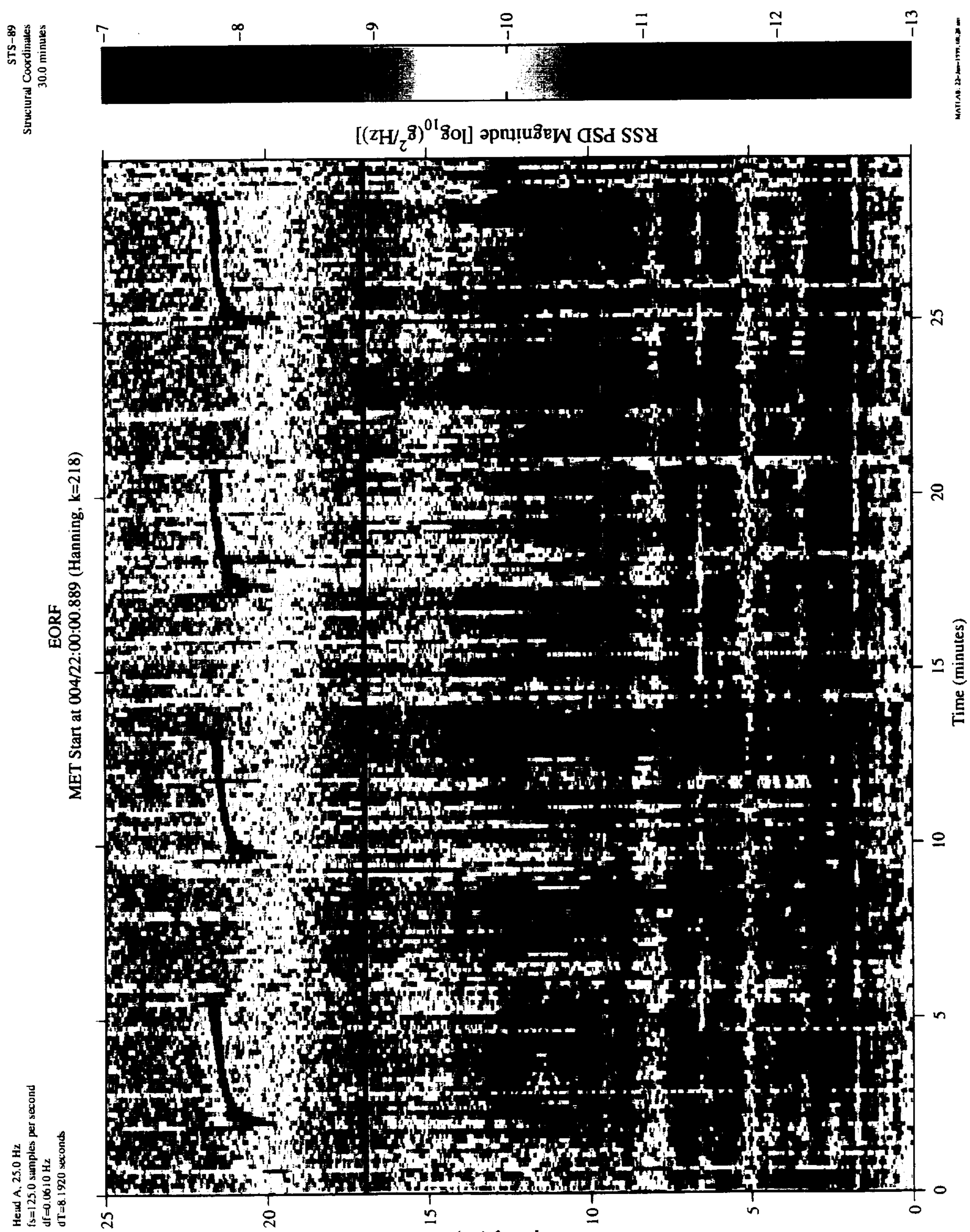


Figure 7. Spectrogram Featuring EORF Signature, STS-89 SAMS TSH A

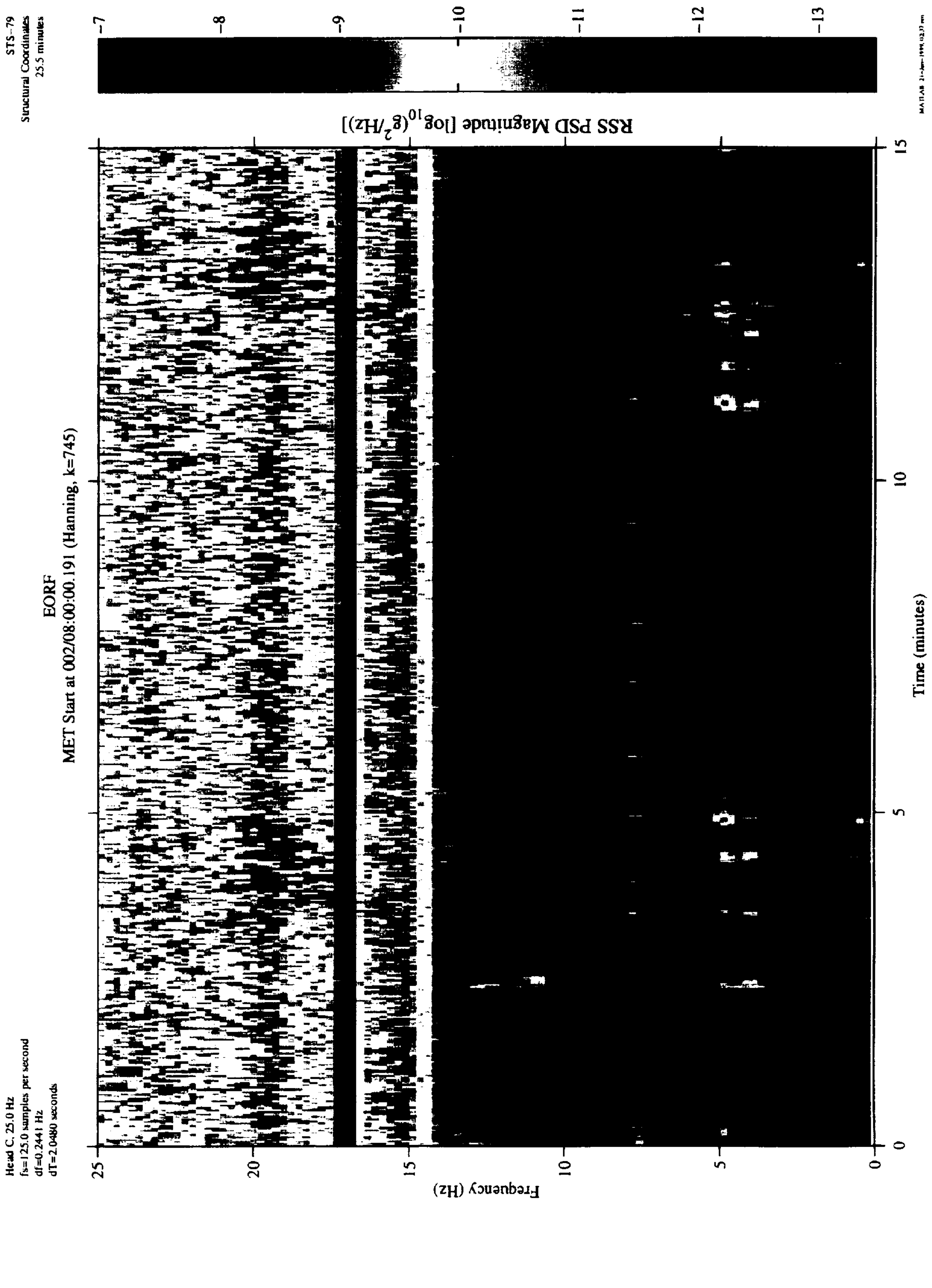


Figure 8. Spectrogram Featuring EORF Signature, STS-79 SAMS TSH C

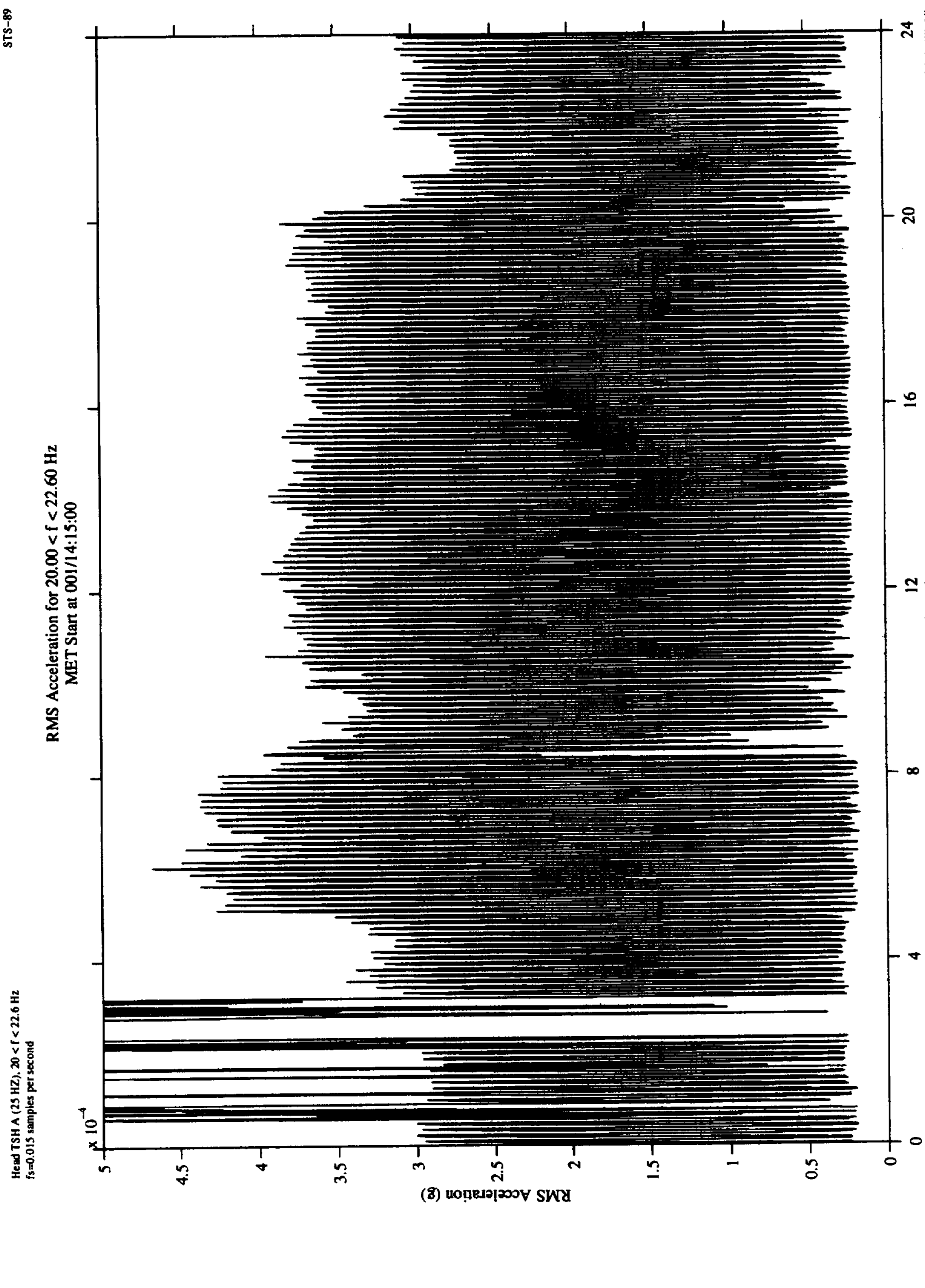


Figure 9. RMS Acceleration Versus Time (20 < f < 22.6 Hz), Orbiter SAMS TSH A

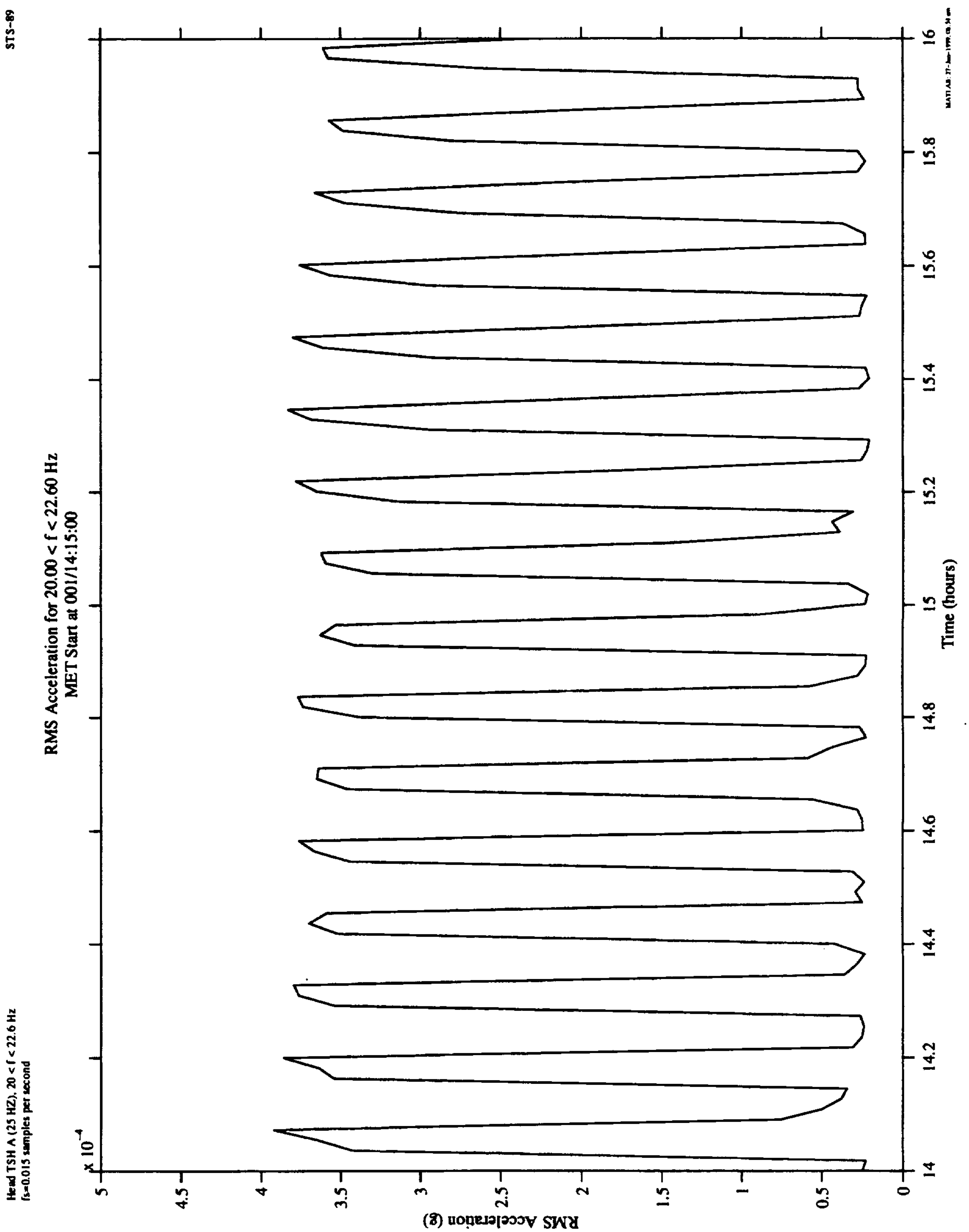


Figure 10. RMS Acceleration Versus Time Zoom (20 < f < 22.6 Hz), Orbiter SAMS TSH A

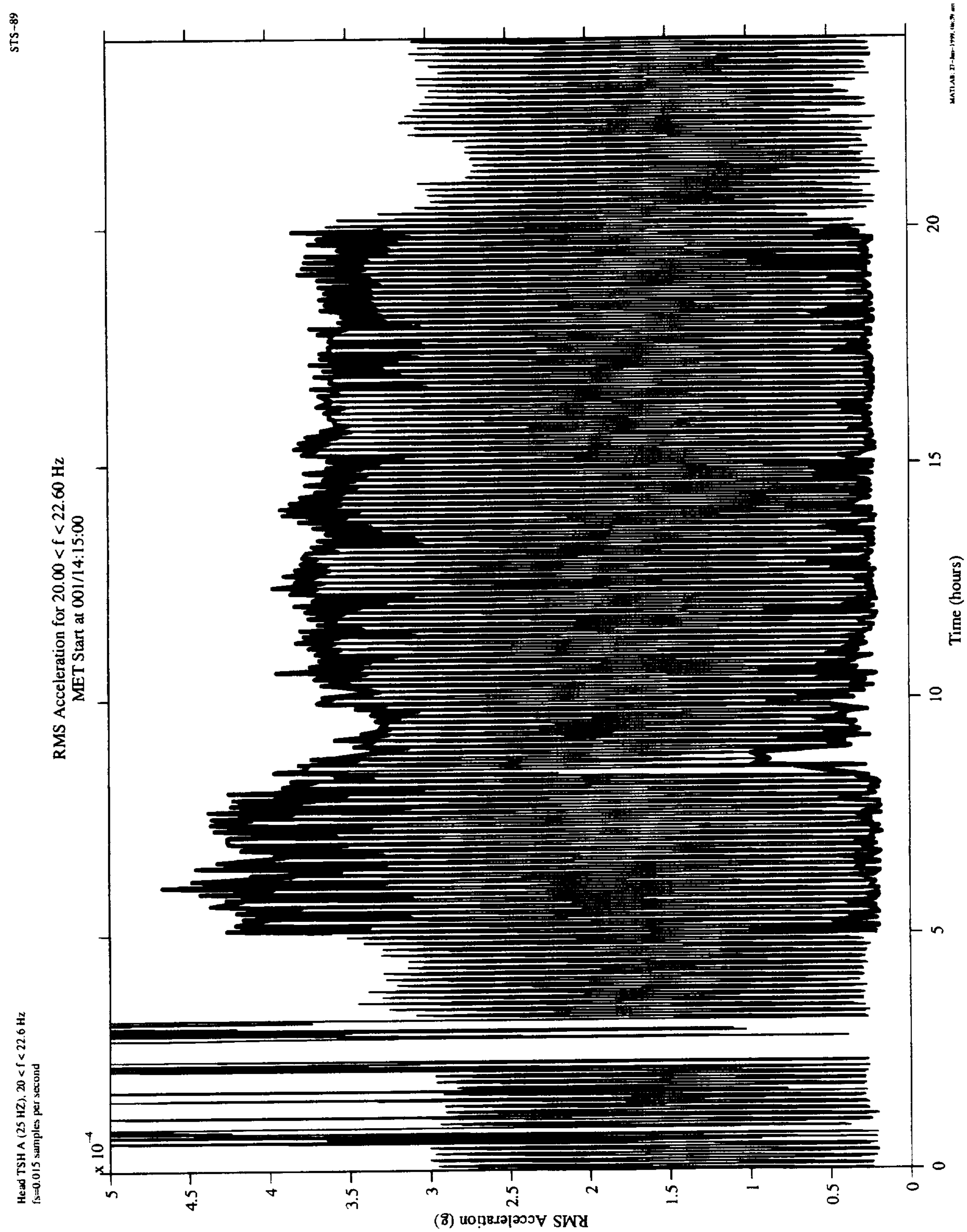


Figure 11. RMS Acceleration Versus Time for EORF Disturbance, Orbiter SAMS TSH A

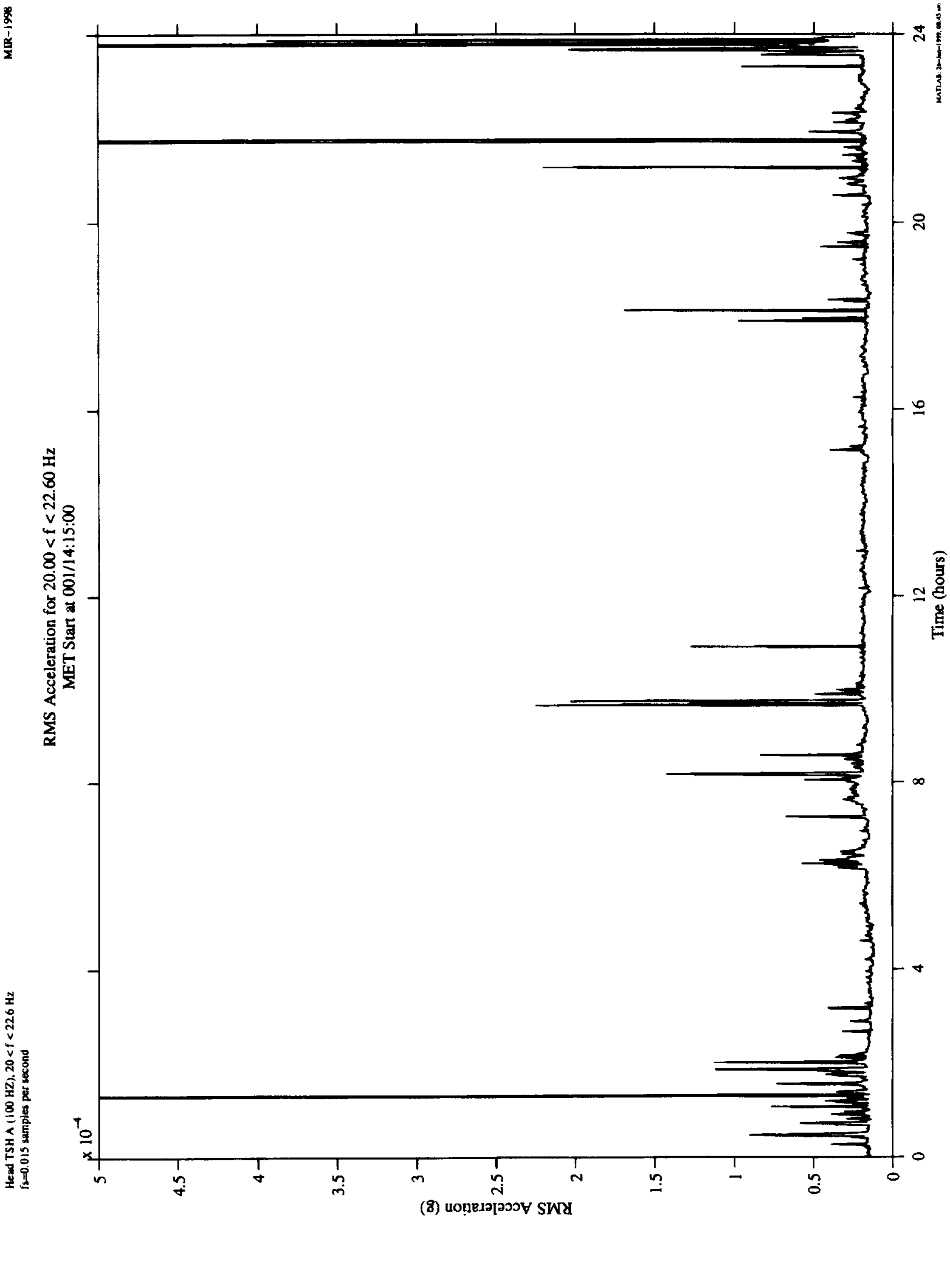


Figure 12. RMS Acceleration Versus Time (20 < f < 22.6 Hz), Mir SAMS TSH A

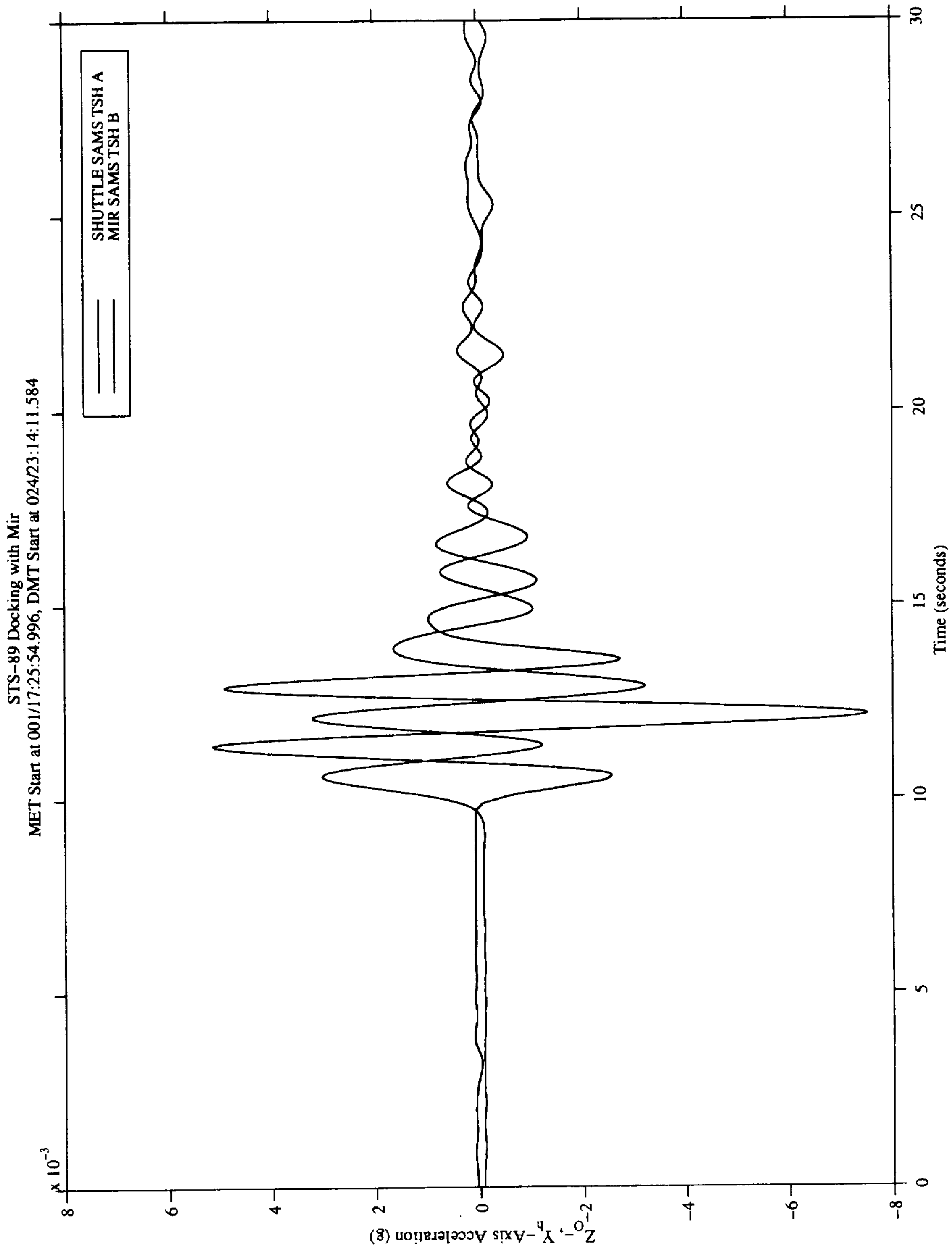


Figure 13. Acceleration Versus Time, STS-89 Docking with Mir

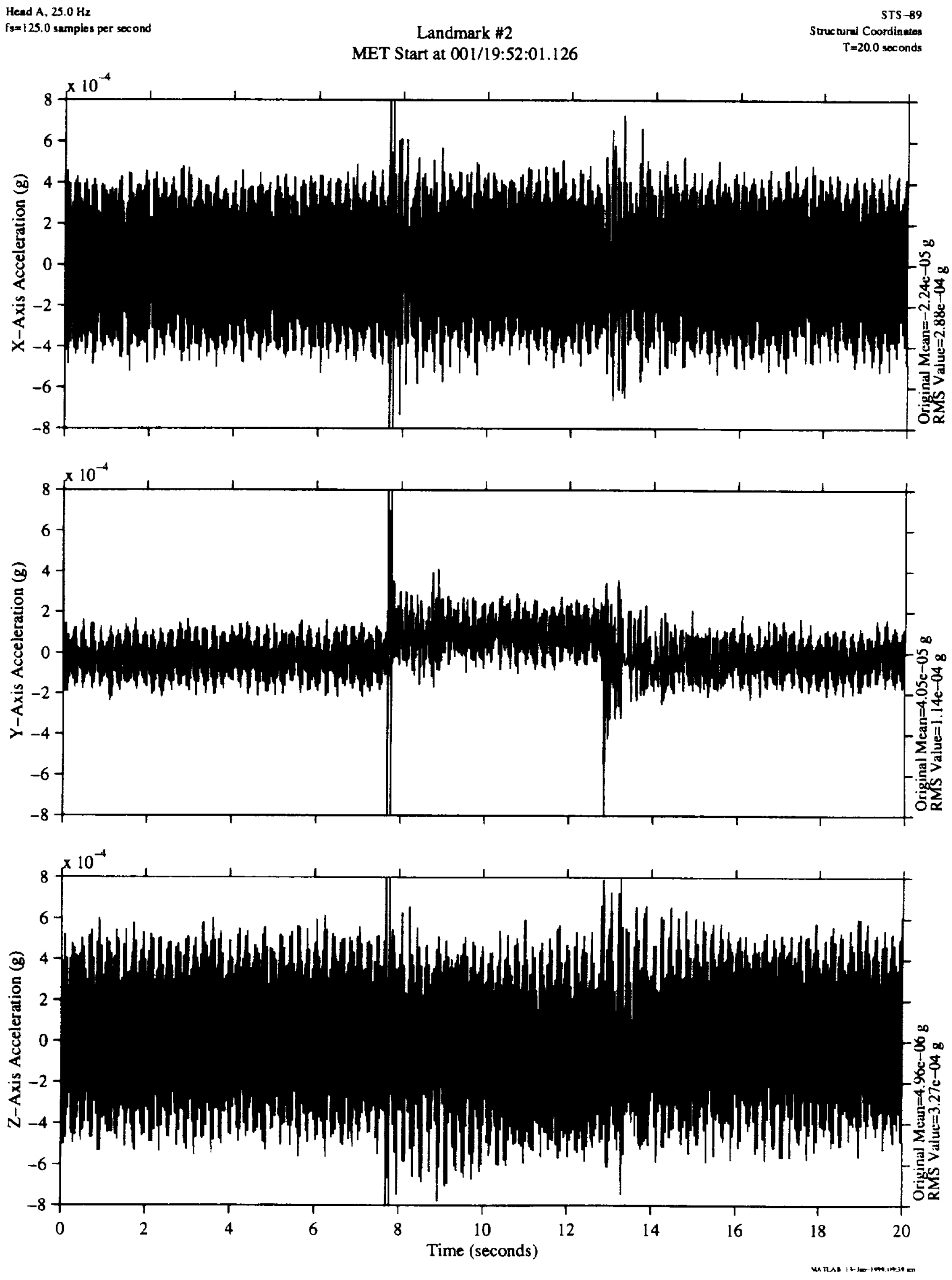


Figure 14. Acceleration Versus Time for Landmark #2, Orbiter SAMS TSH A

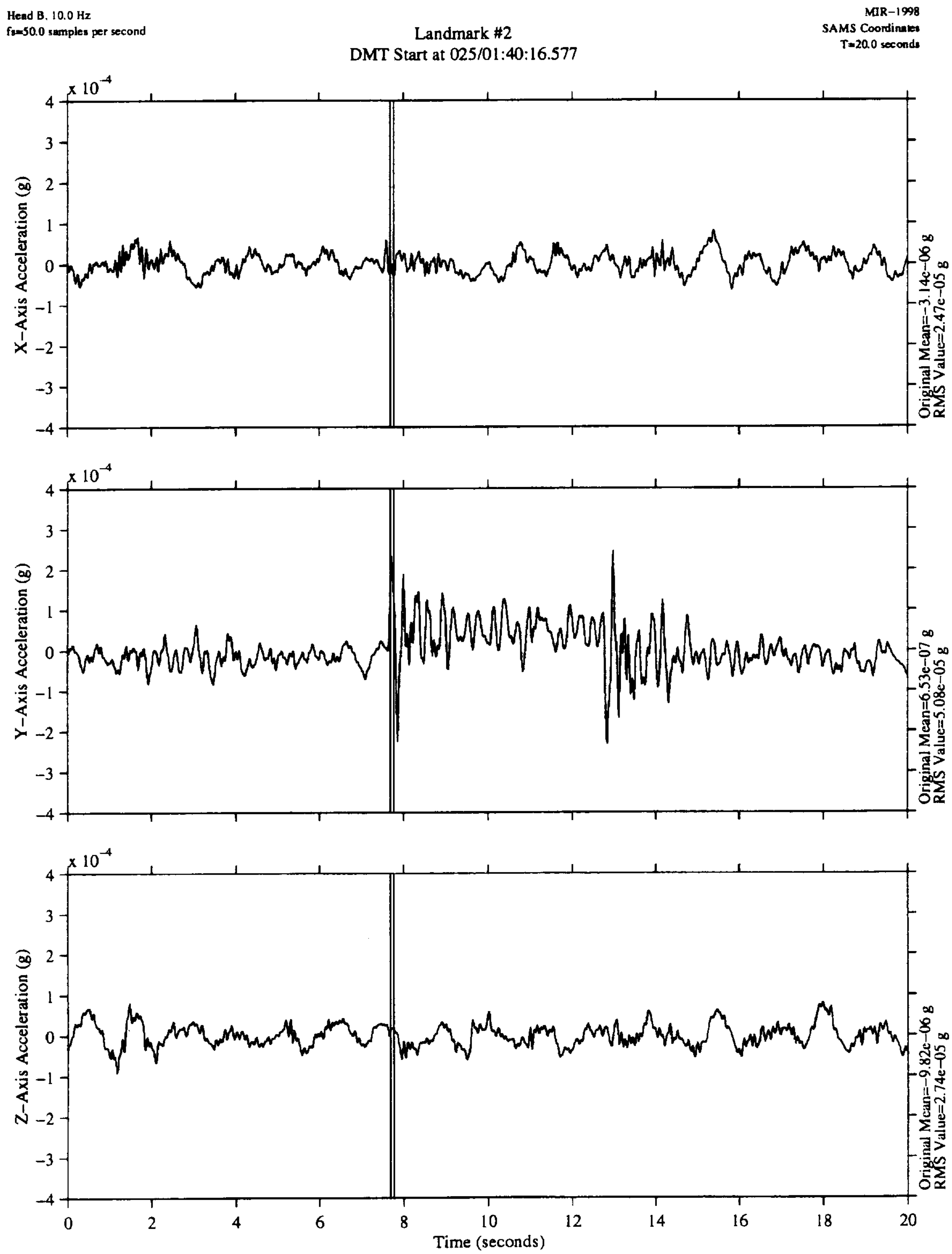


Figure 15. Acceleration Versus Time for Landmark #2, Mir SAMS TSH B

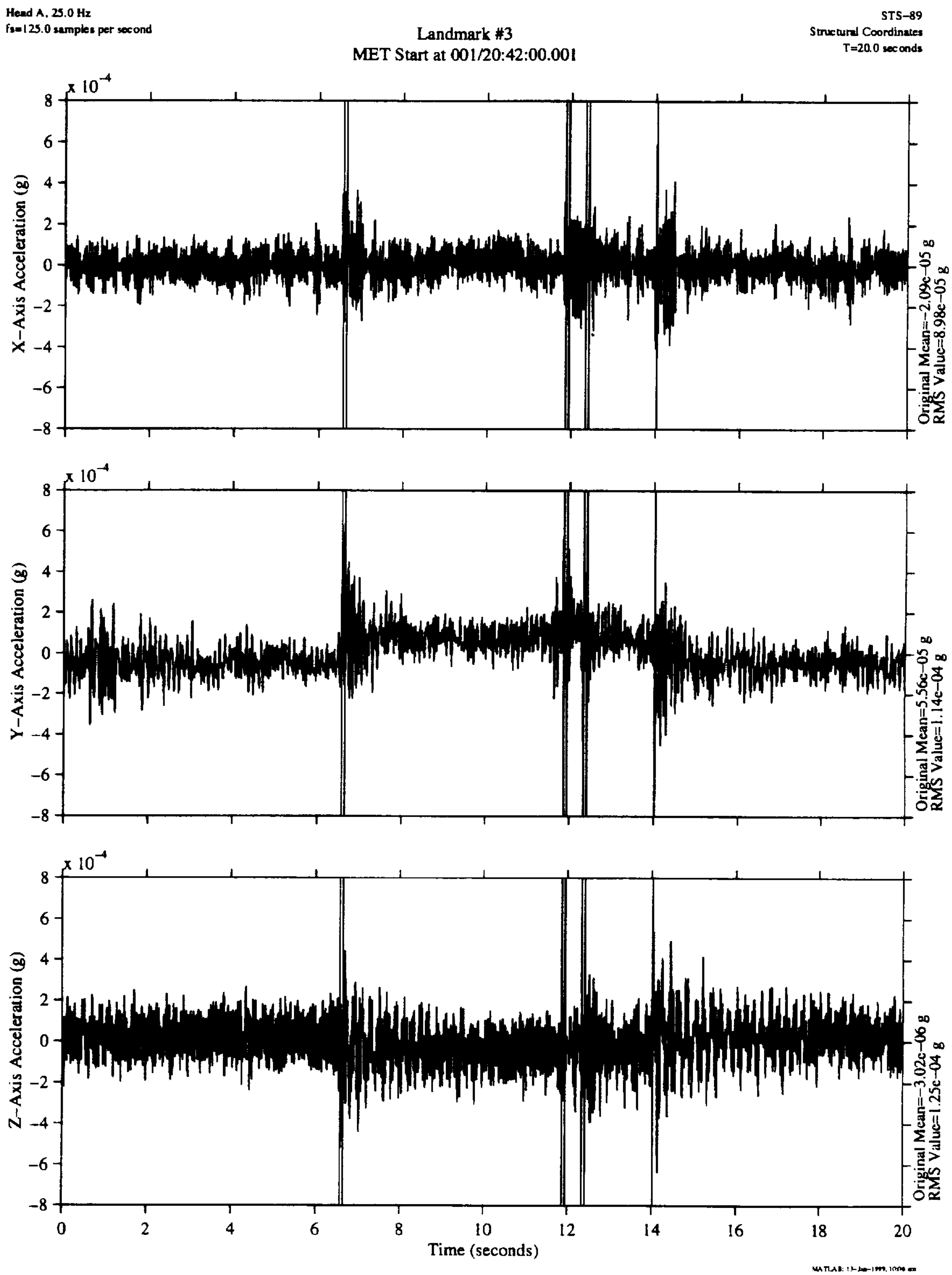


Figure 16. Acceleration Versus Time for Landmark #3, Orbiter SAMS TSH A

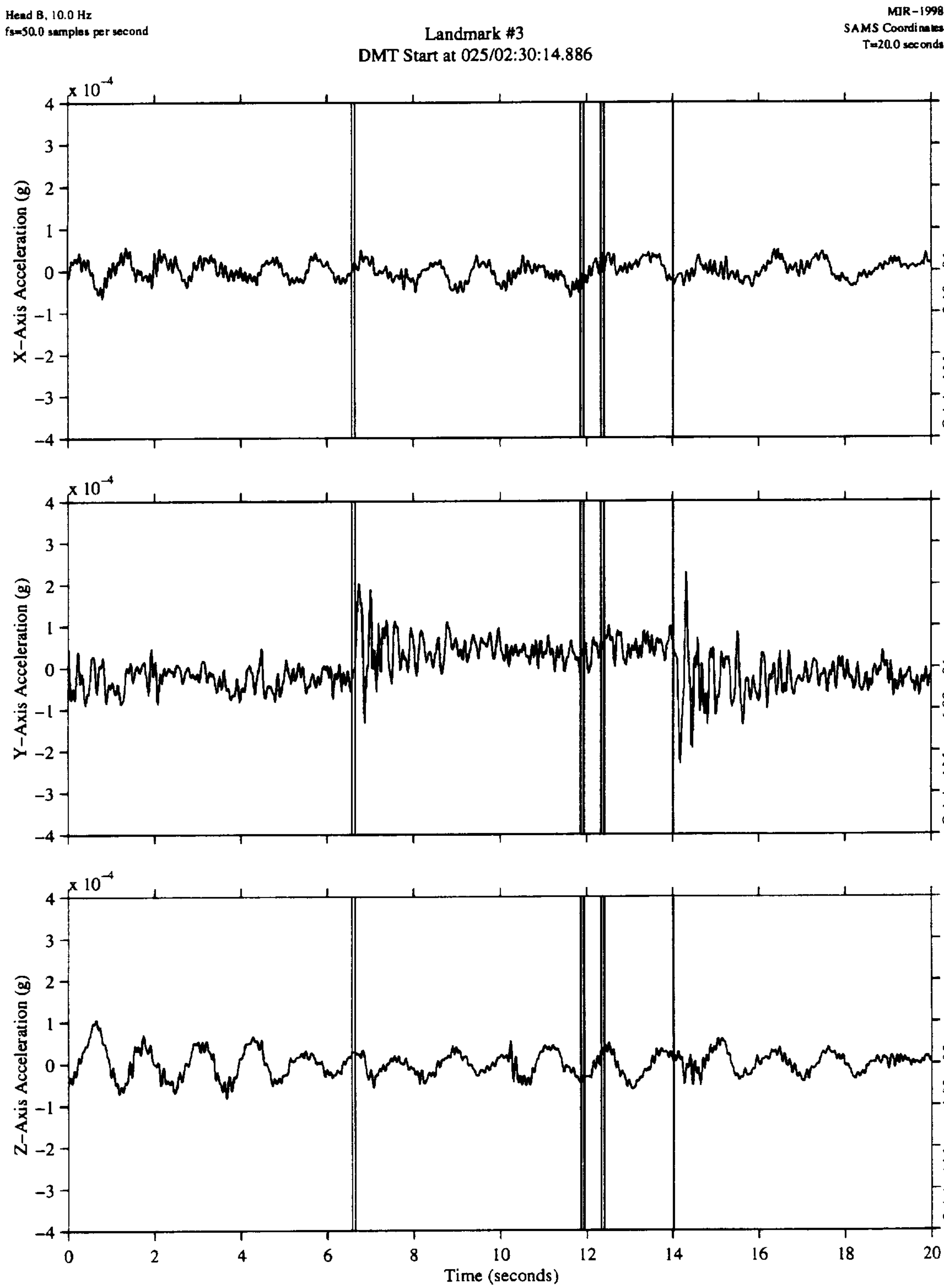


Figure 17. Acceleration Versus Time for Landmark #3, Mir SAMS TSH B

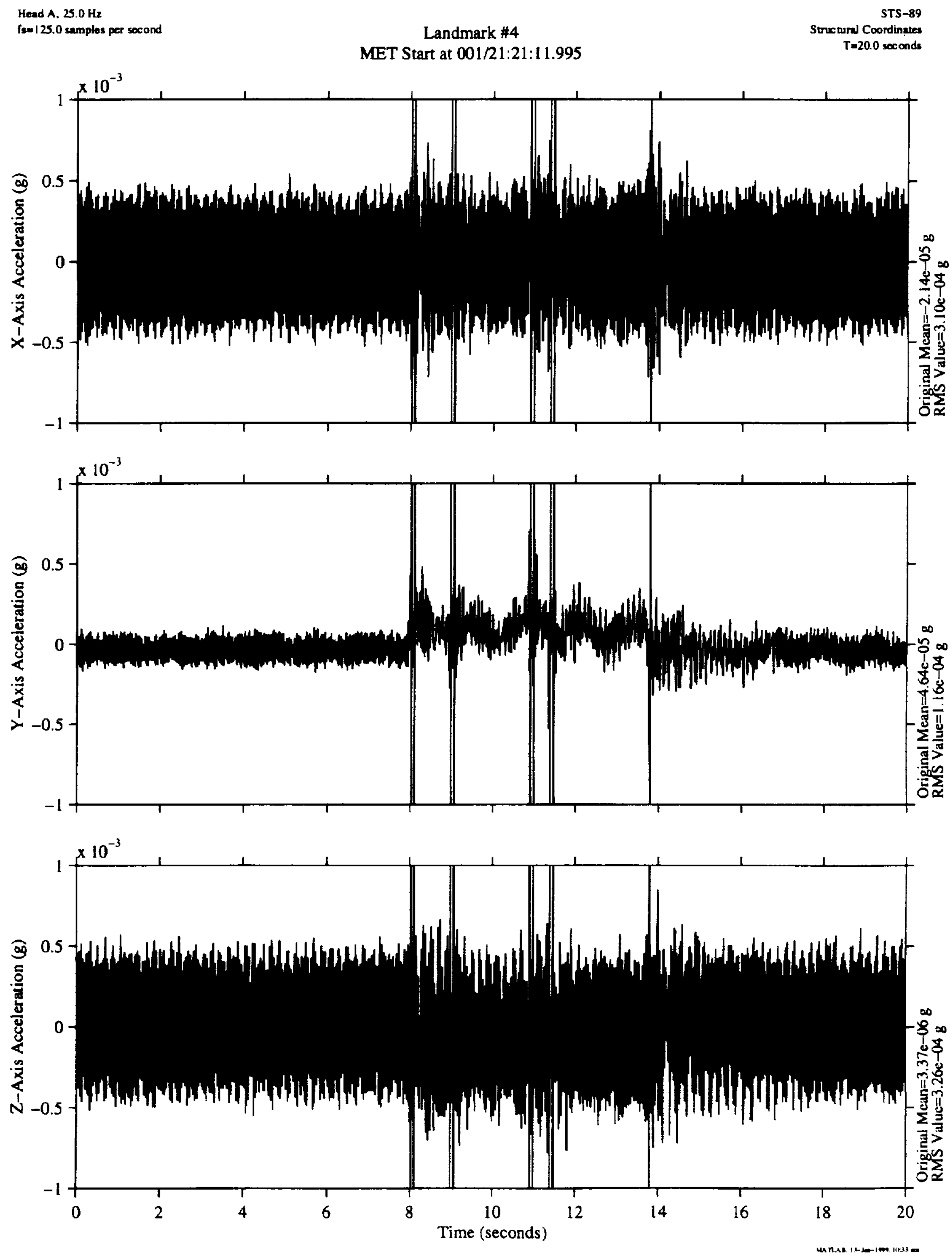


Figure 18. Acceleration Versus Time for Landmark #4, Orbiter SAMS TSH A

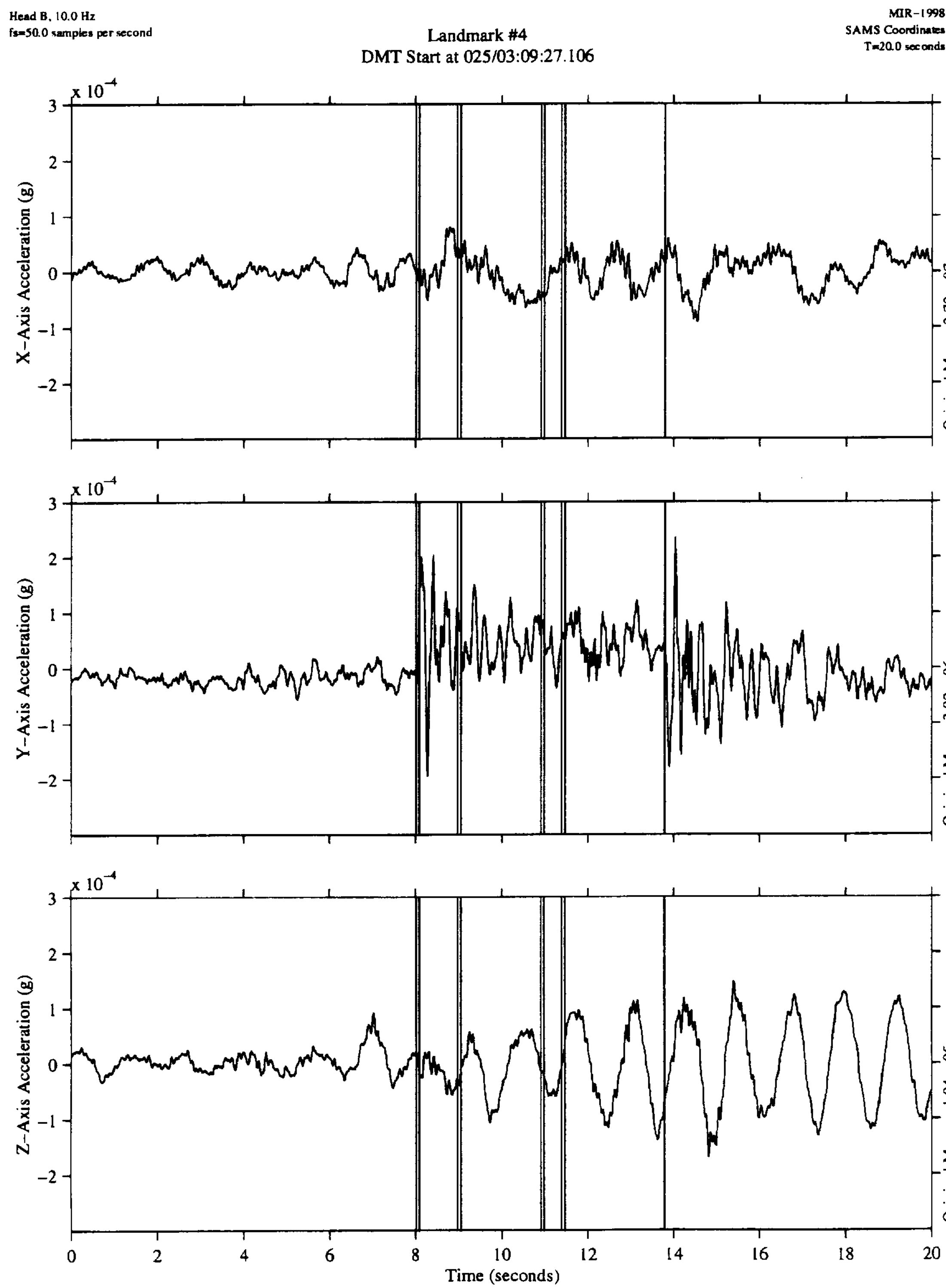


Figure 19. Acceleration Versus Time for Landmark #4, Mir SAMS TSH B

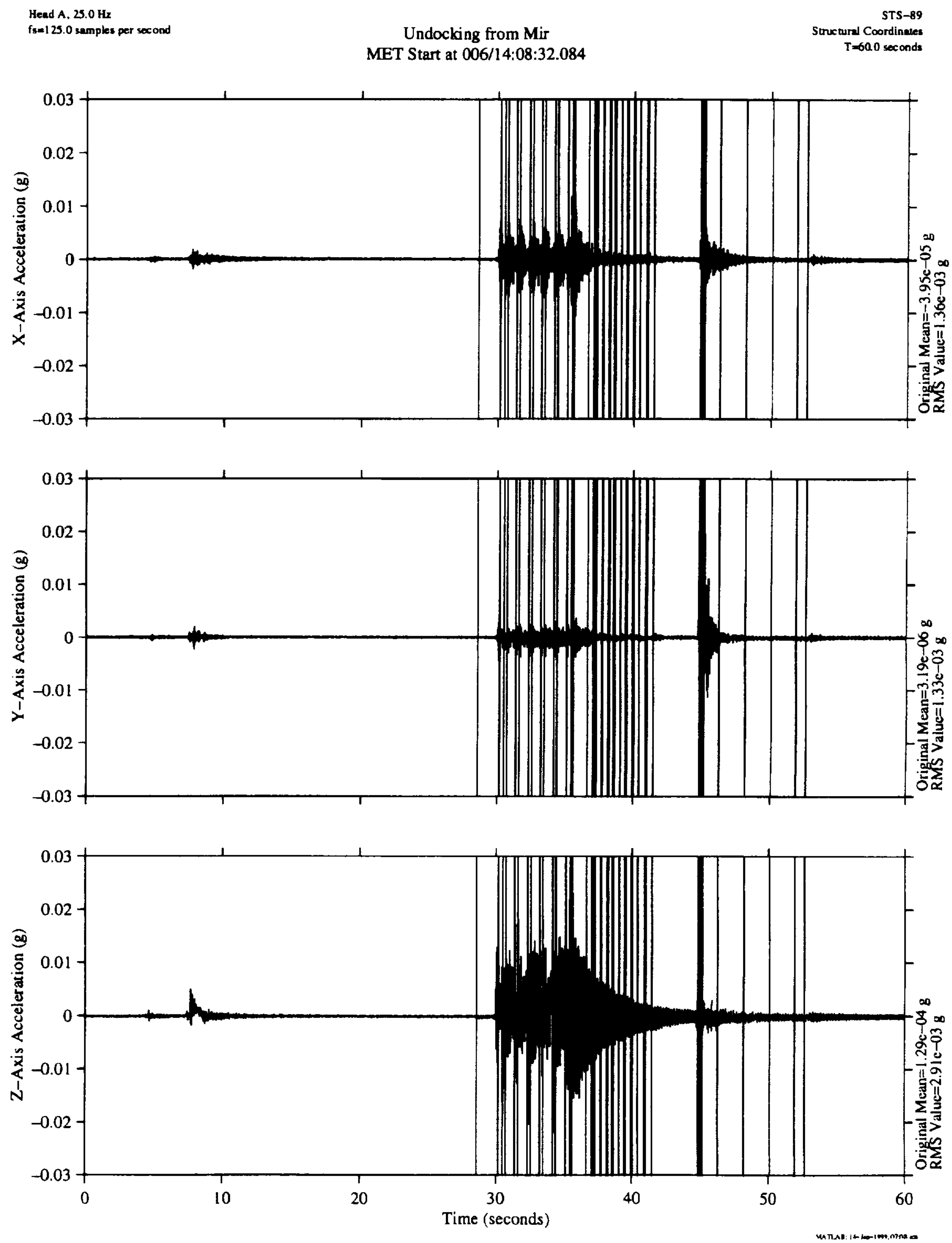


Figure 20. Acceleration Versus Time for Undocking, Orbiter SAMS TSH A

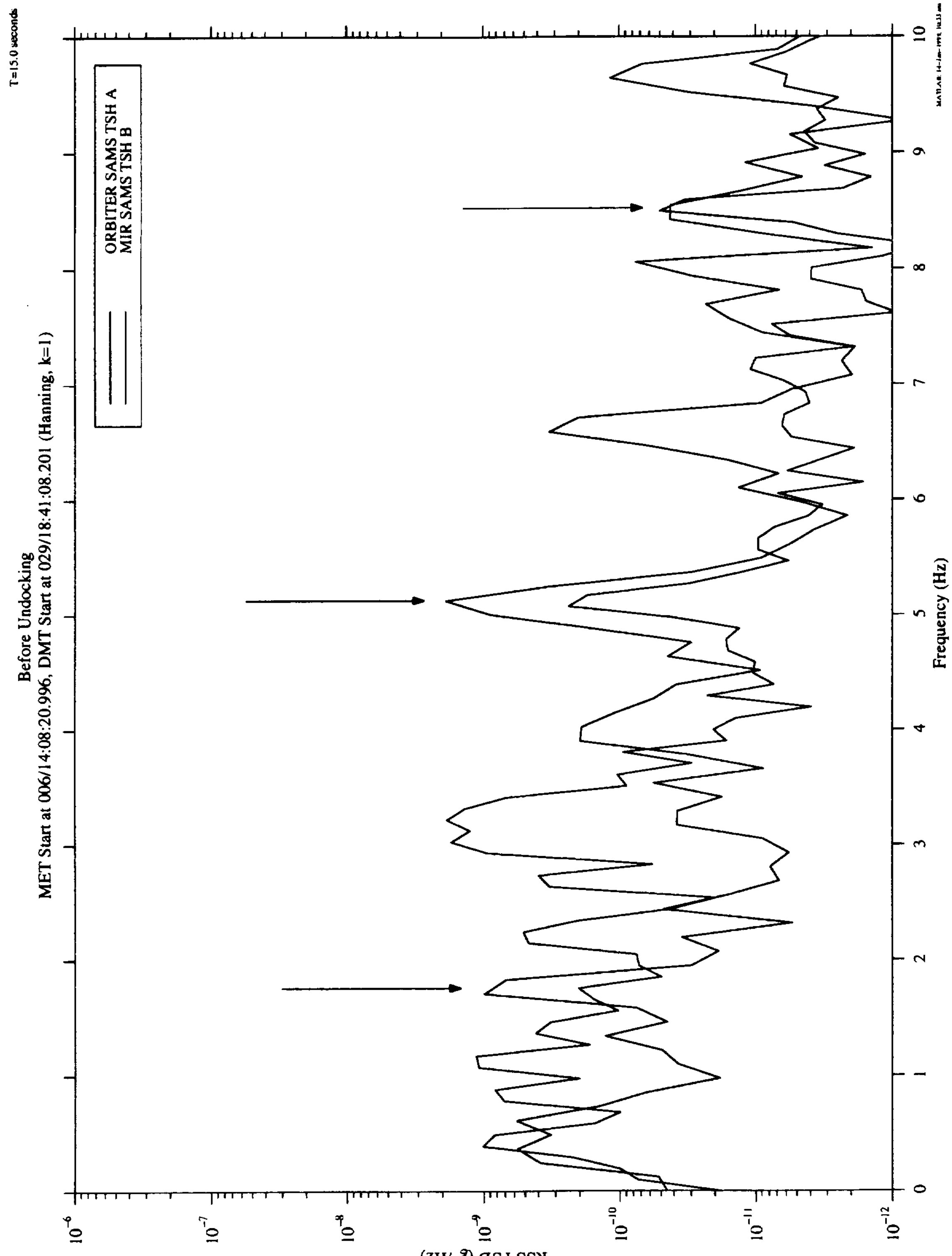


Figure 21. Power Spectral Densities Before Undocking

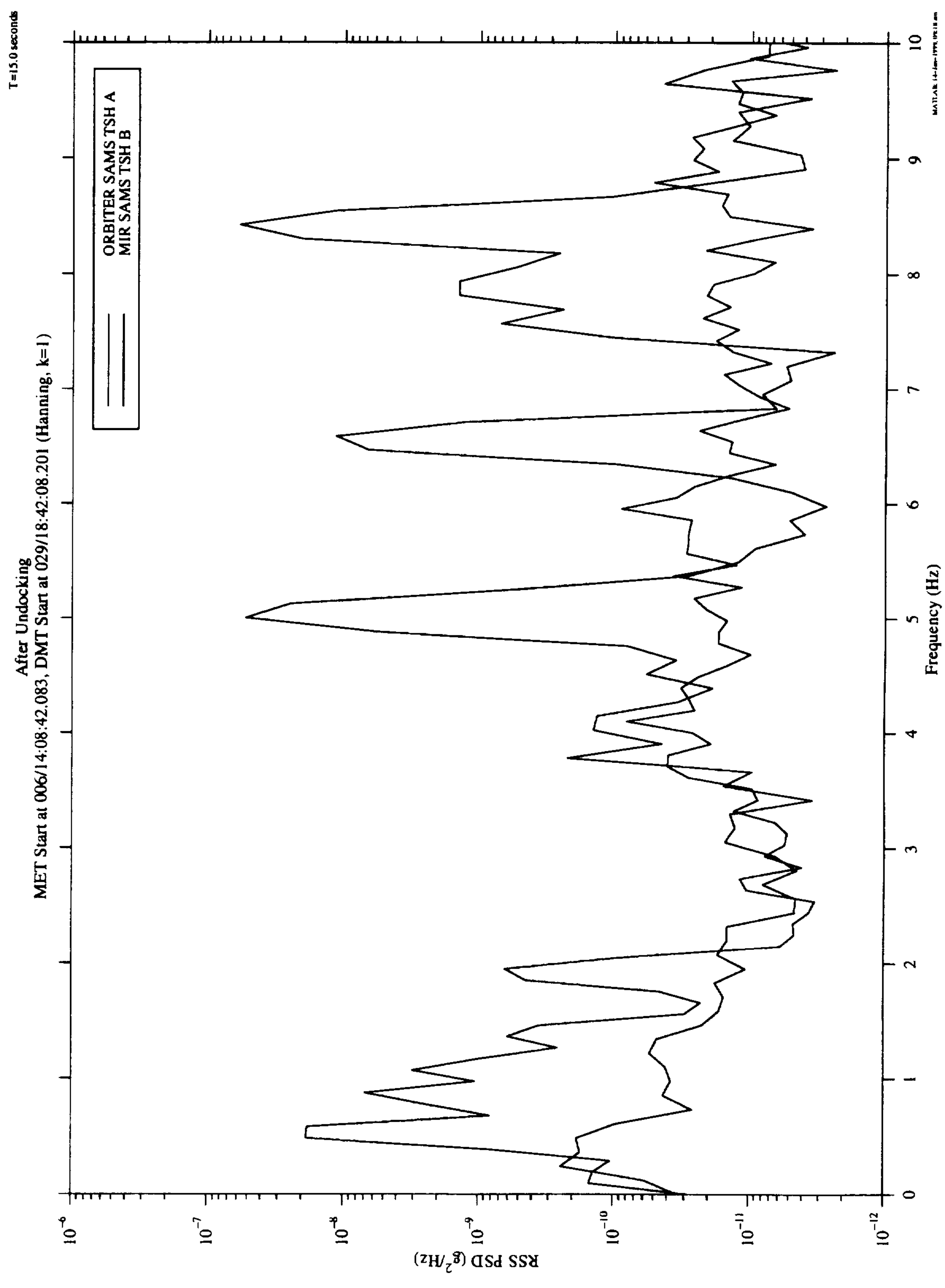


Figure 22. Power Spectral Densities After Undocking

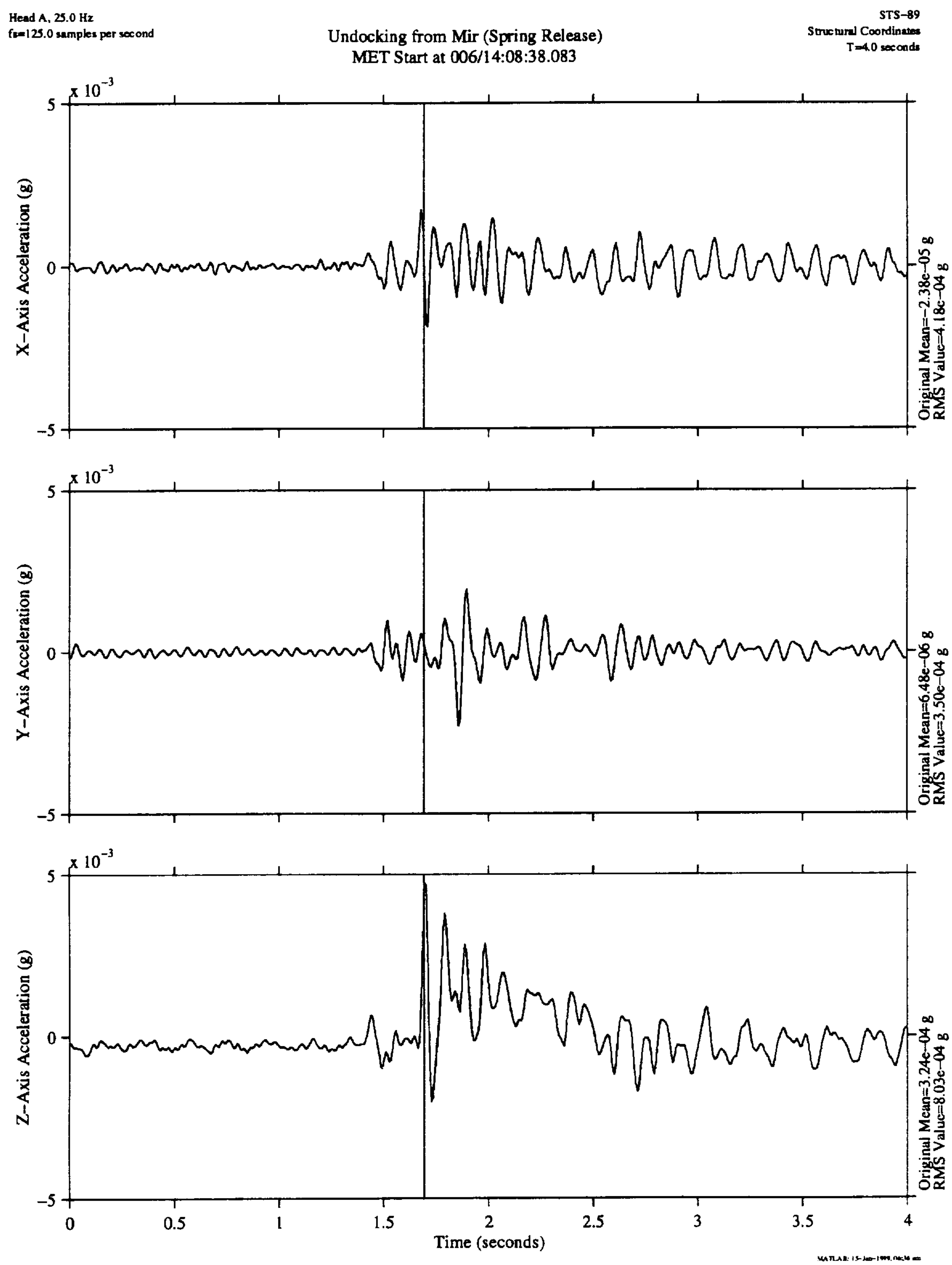


Figure 23. Acceleration Versus Time for Undocking, Orbiter SAMS TSH A

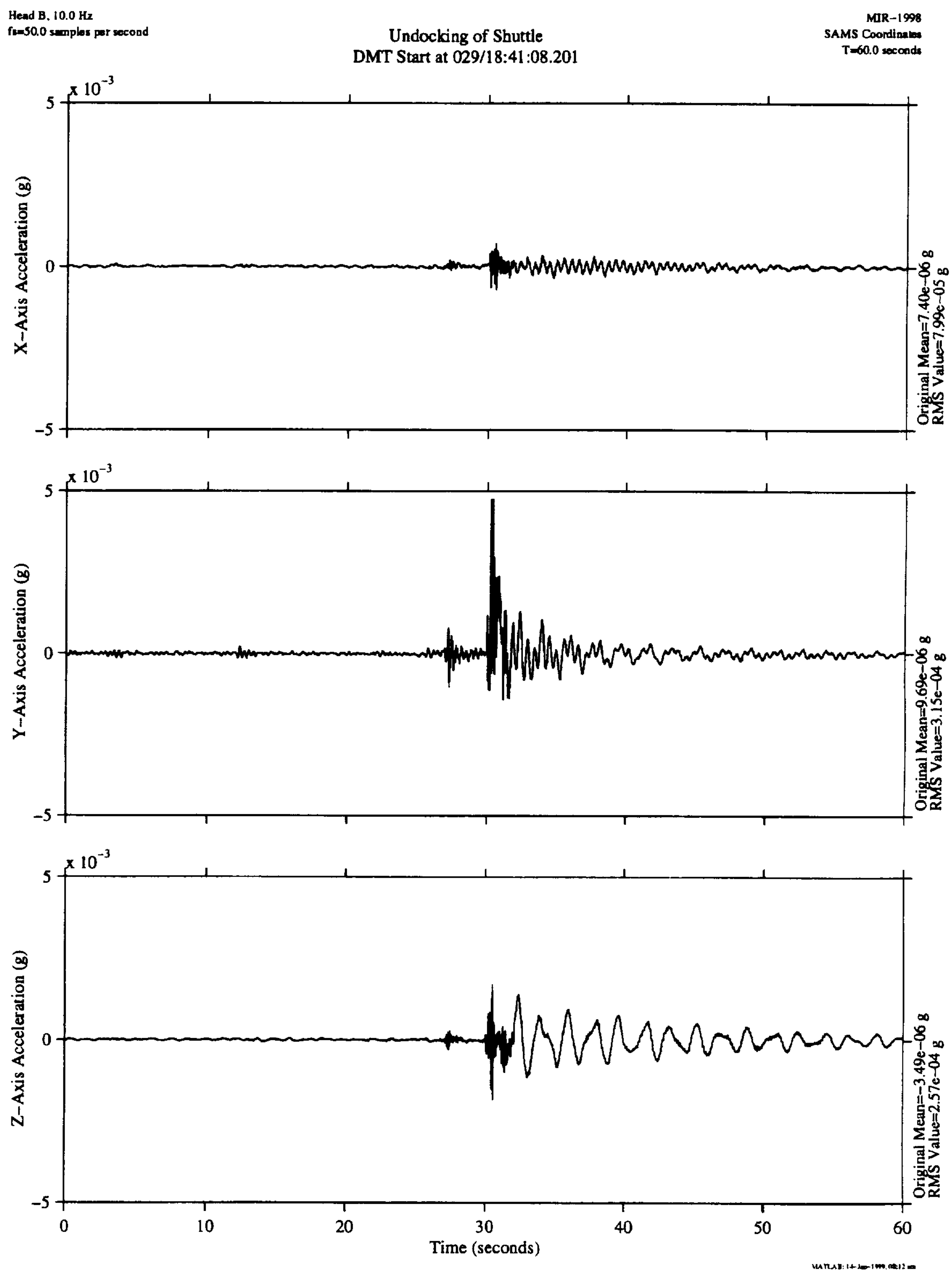


Figure 24. Acceleration Versus Time for Undocking, Mir SAMS TSH B

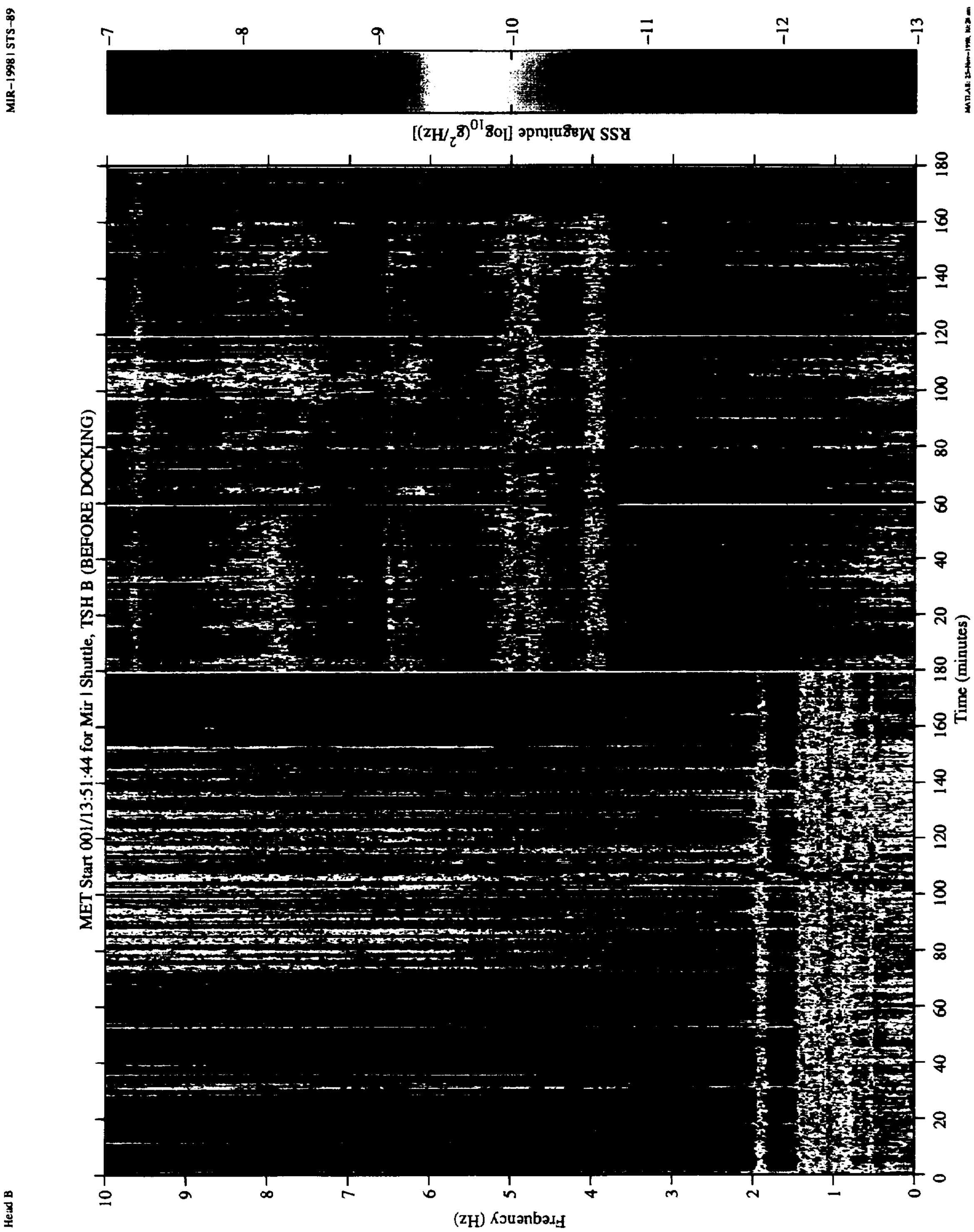


Figure 25. Spectrogram Overlay Before Docking

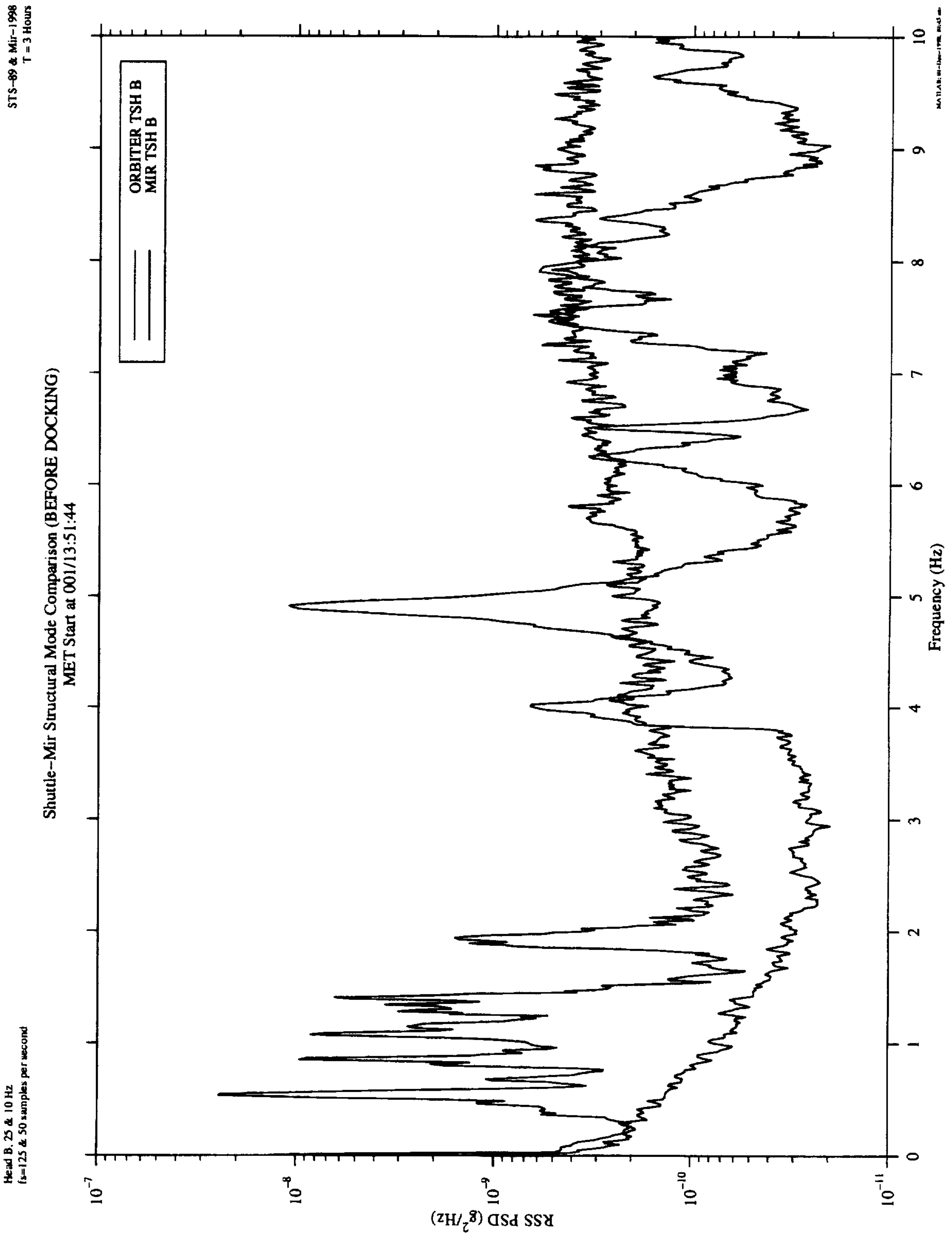


Figure 26. Power Spectral Densities Before Docking

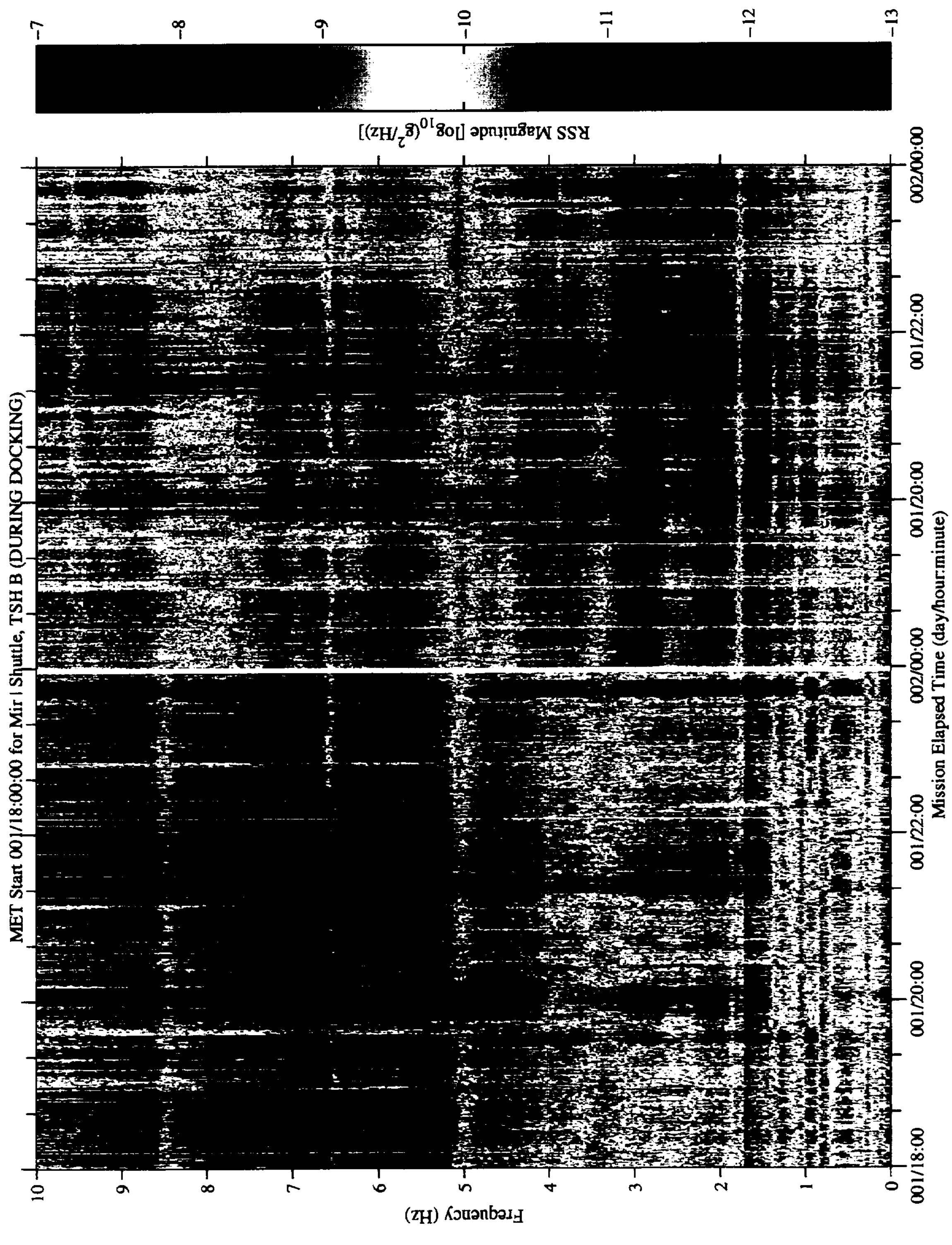


Figure 27. Spectrogram Overlay During Docked Operations

Appendix A - Spectrograms for Orbiter SAMS TSH A (25 Hz)

SAMS TSH A data collected during the STS-89 mission were used to generate the spectrogram plots in this appendix. These data were collected at a rate of 125 samples per second with a lowpass filter cutoff frequency of 25 Hz, which was used as the upper limit on the frequency axis of the plots. With the exception of the first and the last, each spectrogram in this appendix spans a total of 6 hours. The time resolution used to compute the spectrograms was 16.384 seconds, and the frequency resolution was 0.0305 Hz. To produce the spectrogram image, power spectral densities were computed using a Hanning window for successive time intervals. In order to combine all three axes into a single plot, the power spectral densities of the three orthogonal axes were combined in root-sum-of-squares fashion.

These spectrograms are intended to provide a broad overview of how the measured acceleration spectrum varied with time. These plots are not intended for quantitative assessment of the microgravity environment. Other plot types are better suited for this task. Those interested in further details are encouraged to contact the PIMS team.

Appendix B - Spectrograms for Orbiter SAMS TSH B (25 Hz)

SAMS TSH B data collected during the STS-89 mission were used to generate the spectrogram plots in this appendix. These data were collected at a rate of 125 samples per second with a lowpass filter cutoff frequency of 25 Hz, which was used as the upper limit on the frequency axis of the plots. With the exception of the first and the last, each spectrogram in this appendix spans a total of 6 hours. The time resolution used to compute the spectrograms was 16.384 seconds, and the frequency resolution was 0.0305 Hz. To produce the spectrogram image, power spectral densities were computed using a Hanning window for successive time intervals. In order to combine all three axes into a single plot, the power spectral densities of the three orthogonal axes were combined in root-sum-of-squares fashion.

These spectrograms are intended to provide a broad overview of how the measured acceleration spectrum varied with time. These plots are not intended for quantitative assessment of the microgravity environment. Other plot types are better suited for this task. Those interested in further details are encouraged to contact the PIMS team.

Appendix C - Spectrograms for Orbiter SAMS TSH A (62.5 Hz)

SAMS TSH A data collected during the STS-89 mission were used to generate the spectrogram plots in this appendix. These data were collected at a rate of 125 samples per second with a lowpass filter cutoff frequency of 25 Hz. The Nyquist frequency (62.5 Hz) was used as the upper limit on the frequency axis of the plots, so spectral content above 25 Hz has been attenuated by the lowpass filter. With the exception of the first and the last, each spectrogram in this appendix spans a total of 6 hours. The time resolution used to compute the spectrograms was 16.384 seconds, and the frequency resolution was 0.0305 Hz. To produce the spectrogram image, power spectral densities were computed using a Hanning window for successive time intervals. In order to combine all three axes into a single plot, the power spectral densities of the three orthogonal axes were combined in root-sum-of-squares fashion.

These spectrograms are intended to provide a broad overview of how the measured acceleration spectrum varied with time. These plots are not intended for quantitative assessment of the microgravity environment. Other plot types are better suited for this task. Those interested in further details are encouraged to contact the PIMS team.

Appendix D - Spectrograms for Orbiter SAMS TSH B (62.5 Hz)

SAMS TSH B data collected during the STS-89 mission were used to generate the spectrogram plots in this appendix. These data were collected at a rate of 125 samples per second with a lowpass filter cutoff frequency of 25 Hz. The Nyquist frequency (62.5 Hz) was used as the upper limit on the frequency axis of the plots, so spectral content above 25 Hz has been attenuated by the lowpass filter. With the exception of the first and the last, each spectrogram in this appendix spans a total of 6 hours. The time resolution used to compute the spectrograms was 16.384 seconds, and the frequency resolution was 0.0305 Hz. To produce the spectrogram image, power spectral densities were computed using a Hanning window for successive time intervals. In order to combine all three axes into a single plot, the power spectral densities of the three orthogonal axes were combined in root-sum-of-squares fashion.

These spectrograms are intended to provide a broad overview of how the measured acceleration spectrum varied with time. These plots are not intended for quantitative assessment of the microgravity environment. Other plot types are better suited for this task. Those interested in further details are encouraged to contact the PIMS team.

Appendix E - Spectrograms for Mir SAMS TSH A (25 Hz)

SAMS TSH A data collected on Mir during docked operations with the STS-89 mission were used to generate the spectrogram plots in this appendix. These data were collected at a rate of 500 samples per second with a lowpass filter cutoff frequency of 100 Hz. A frequency of 25 Hz was used as the upper limit on the frequency axis of these plots for direct comparison with the data collected on Endeavour. With the exception of the first and the last, each spectrogram in this appendix spans a total of 6 hours. The time resolution used to compute the spectrograms was 16.384 seconds, and the frequency resolution was 0.0305 Hz. The time axis is shown in terms of STS-89 MET, while the data were collected with DMT timestamps. To convert from DMT to STS-89 MET the following time was subtracted from the DMT recorded times: 023/05:48:15. The converted time is what is shown on the spectrograms' time axis. To produce the spectrogram image, power spectral densities were computed using a Hanning window for successive time intervals. In order to combine all three axes into a single plot, the power spectral densities of the three orthogonal axes were combined in root-sum-of-squares fashion.

These spectrograms are intended to provide a broad overview of how the measured acceleration spectrum varied with time. These plots are not intended for quantitative assessment of the microgravity environment. Other plot types are better suited for this task. Those interested in further details are encouraged to contact the PIMS team.

Appendix F - Spectrograms for Mir SAMS TSH B (10 Hz)

SAMS TSH B data collected on Mir during docked operations with the STS-89 mission were used to generate the spectrogram plots in this appendix. These data were collected at a rate of 50 samples per second with a lowpass filter cutoff frequency of 10 Hz. The cutoff frequency was used as the upper limit on the frequency axis of these plots. With the exception of the first and the last, each spectrogram in this appendix spans a total of 6 hours. The time resolution used to compute the spectrograms was 20.48 seconds, and the frequency resolution was 0.0244 Hz. The time axis is shown in terms of STS-89 MET, while the data were collected with DMT times. To convert from DMT to STS-89 MET the following time was subtracted from the DMT recorded times: 023/05:48:15. The converted time is what is shown on the spectrograms' time axis. To produce the spectrogram image, power spectral densities were computed using a Hanning window for successive time intervals. In order to combine all three axes into a single plot, the power spectral densities of the three orthogonal axes were combined in root-sum-of-squares fashion.

These spectrograms are intended to provide a broad overview of how the measured acceleration spectrum varied with time. These plots are not intended for quantitative assessment of the microgravity environment. Other plot types are better suited for this task. Those interested in further details are encouraged to contact the PIMS team.

Appendix G - Interval Min/Max Plots for MGM Experiment Times (Orbiter SAMS TSH A)

For post-mission correlation with science data acquired for the MGM experiment, the SAMS TSH A data collected on Endeavour were analyzed using 1-second interval min/max plots for a number of experiment run time frames totaling more than 25 hours. The plots in this appendix are the set for TSH A. The MGM science requirement threshold is shown on the plots as the horizontal dashed lines at ± 1 mg. The overall min/max values on a per plot basis are shown with the text to the right of each axis' plot with the corresponding times that the min/max values occurred, respectively.

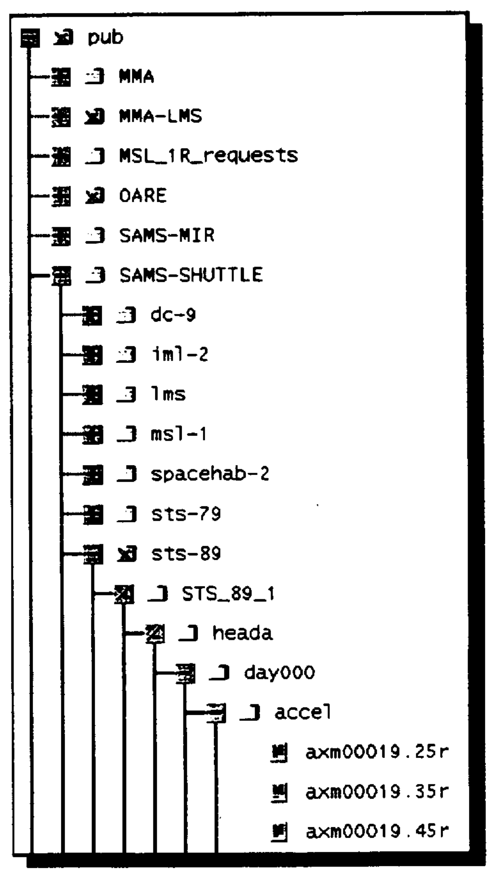
Appendix H - Interval Min/Max Plots for MGM Experiment Times (Orbiter SAMS TSH B)

For post-mission correlation with science data acquired for the MGM experiment, the SAMS TSH B data collected on Endeavour were analyzed using 1-second interval min/max plots for a number of experiment run time frames totaling more than 25 hours. The plots in this appendix are the set for TSH B. The MGM science requirement threshold is shown on the plots as the horizontal dashed lines at ± 1 mg. The overall min/max values on a per plot basis are shown with the text to the right of each axis' plot with the corresponding times that the min/max values occurred, respectively.

Appendix I - Accessing Acceleration Data Via the Internet

SAMS data collected both on Endeavour and Mir during the STS-89 mission are available over the Internet from a NASA Glenn Research Center file server with hostname beech.grc.nasa.gov. Acceleration data and related files are arranged in a tree structure. The figure shown below illustrates this structure. The acceleration data files (located at the end of the tree structure) are named for the contents of the file. For example, a file named "axm00019.25r" in the directory "/pub/SAMS-SHUTTLE/sts-89/STS_89_1/heada/day000/accel" would contain TSH A data for the X-axis for day 001, hour 19, file 2 of 5. The readme.doc file in the STS_89_1 directory gives a complete explanation of the file naming convention. The beech file server can be accessed via anonymous file transfer protocol (ftp), as follows:

1. Open a connection to the file server (hostname: beech.grc.nasa.gov)
2. Login with username: anonymous
3. Enter your complete e-mail address as the password
4. Navigate to the directory containing the desired files (like the path shown here: /pub/SAMS-SHUTTLE/sts-89/STS_89_1/heada/day000/accel)
5. Enable binary file transfer
6. Transfer the desired files
7. Close the connection



If you encounter difficulty in accessing the data using the file server, send an electronic mail message to pims@grc.nasa.gov. Please describe the nature of the difficulty and give a description of the hardware and software you are using to access the file server, including the domain name and/or IP address from which you are connecting.

Appendix J - Reader Feedback

The PIMS team aims to provide information such as that contained in this report to the microgravity community in a form that is most helpful. To help us with this goal, we ask that you please answer the following questions and respond with any other feedback you may have:

1. Does this report fulfill your requirements for acceleration-related mission information?

______Yes ______No If no, then please explain?

____

____

____

____

2. Is there information in this report that you feel was not necessary or useful?

______No ______Yes If yes, then what should have been excluded and why?

____

____

____

____

3. Are there any specific analyses or data access needs you have regarding the acceleration data that have not been addressed?

______No ______Yes If yes, then please provide the details and PIMS will respond.

____

____

____

____

Completed by: (Thank you)

Name:______________________

Address:______________________

____

Telephone:______________________

Fax:______________________

E-mail:______________________

Please return this sheet to:

PIMS Project Manager
NASA Glenn Research Center
21000 Brookpark Road MS 500-216
Cleveland, OH 44135

or, submit by:

Fax to PIMS Project: 216-433-8660
E-mail to: pims@grc.nasa.gov
Online form at URL shown below.

http://www.grc.nasa.gov/WWW/MMAP/PIMS/HTMLS/MSRs/STS-89/response.html

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	June 1999	Technical Memorandum

4. TITLE AND SUBTITLE

Summary Report of Mission Acceleration Measurements for STS–89

5. FUNDING NUMBERS

WU–101–46–0A–00

6. AUTHOR(S)

Kenneth Hrovat and Kevin McPherson

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
John H. Glenn Research Center at Lewis Field
Cleveland, Ohio 44135–3191

8. PERFORMING ORGANIZATION REPORT NUMBER

E–11667

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Washington, DC 20546–0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

NASA TM—1999-209084

11. SUPPLEMENTARY NOTES

Kenneth Hrovat, Tal-Cut Company, 24831 Lorain Road, Suite 203, North Olmsted, Ohio, 44070 (work funded under NAS3–27254) and Kevin McPherson, NASA Glenn Research Center. Responsible person, Kenneth Hrovat, organization code 6727, (216) 433–3564.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified - Unlimited
Subject Categories: 20, 35, and 18 Distribution: Nonstandard

This publication is available from the NASA Center for AeroSpace Information, (301) 621–0390.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Support of microgravity research on the 89th flight of the Space Transportation System (STS-89) and a continued effort to characterize the acceleration environment of the Space Shuttle Orbiter and the Mir Space Station form the basis for this report. For the STS-89 mission, the Space Shuttle Endeavour was equipped with a Space Acceleration Measurement System (SAMS) unit, which collected more than a week's worth of data. During docked operations with Mir, a second SAMS unit collected approximately a day's worth of data yielding the only set of acceleration measurements recorded simultaneously on the two spacecraft. Based on the data acquired by these SAMS units, this report serves to characterize a number of acceleration events and quantify their impact on the local nature of the accelerations experienced at the Mechanics of Granular Materials (MGM) experiment location. Crew activity was shown to nearly double the median root-mean-square (RMS) acceleration level calculated below 10 Hz, while the Enhanced Orbiter Refrigerator/Freezer operating at about 22 Hz was a strong acceleration source in the vicinity of the MGM location. The MGM science requirement that the acceleration not exceed ± 1 mg was violated numerous times during their experiment runs; however, no correlation with sample instability has been found to this point. Synchronization between the SAMS data from Endeavour and from Mir was shown to be close much of the time, but caution with respect to exact timing should be exercised when comparing these data. When orbiting as a separate vehicle prior to docking, Endeavour had prominent structural modes above 3 Hz, while Mir exhibited a cluster of modes around 1 Hz. When mated, a transition to common modes was apparent in the two SAMS data sets. This report is not a comprehensive analysis of the acceleration data, so those interested in further details should contact the Principal Investigator Microgravity Services team at the National Aeronautics and Space Administration's John H. Glenn Research Center.

14. SUBJECT TERMS

Accelerometer; Data analysis; Time domain; Frequency domain; Microgravity environment

15. NUMBER OF PAGES 68

16. PRICE CODE A04

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

Appendix K - Contents of Supplemental CD-ROM

This document is also available in electronic form on the supplemental CD-ROM. The files found on the CD-ROM are in Adobe's Portable Document Format (PDF) and are listed below:

Contents		Filename
Summary Report of Mission Acceleration Measurements for STS-89		sts89.pdf
Appendix A	Spectrograms for Orbiter SAMS TSH A (25 Hz)	sts89a.pdf
Appendix B	Spectrograms for Orbiter SAMS TSH B (25 Hz)	sts89b.pdf
Appendix C	Spectrograms for Orbiter SAMS TSH A (62.5 Hz)	sts89c.pdf
Appendix D	Spectrograms for Orbiter SAMS TSH B (62.5 Hz)	sts89d.pdf
Appendix E	Spectrograms for Mir SAMS TSH A (25 Hz)	sts89e.pdf
Appendix F	Spectrograms for Mir SAMS TSH B (10 Hz)	sts89f.pdf
Appendix G	Interval Min/Max Plots for MGM Experiment Times (Orbiter SAMS TSH A)	sts89g.pdf
Appendix H	Interval Min/Max Plots for MGM Experiment Times (Orbiter SAMS TSH B)	sts89h.pdf
Appendix I	Accessing Acceleration Data Via the Internet	sts89i.pdf
Appendix J	Reader Feedback (see URL near bottom of page for online form)	sts89j.pdf
Summary Report of Mission Acceleration Measurements for STS-79		sts79.pdf

The Acrobat Directory contains copies of the Acrobat Reader application that you may download onto your computer, if needed.